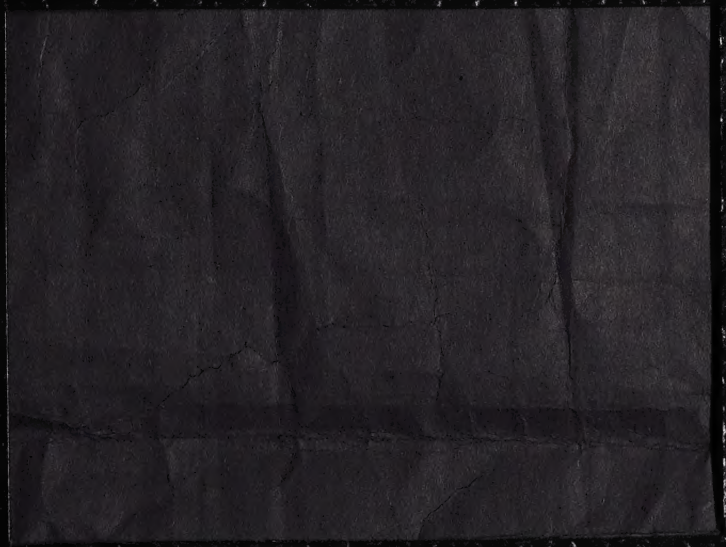




Electronic Services - Los Angeles
M13271X



GENERAL  ELECTRIC



KEPCO

OPERATIONAL POWER SUPPLIES

OPS
group IV-V

Model OPS 100-1M

Serial No. *E. 92269*

instruction manual

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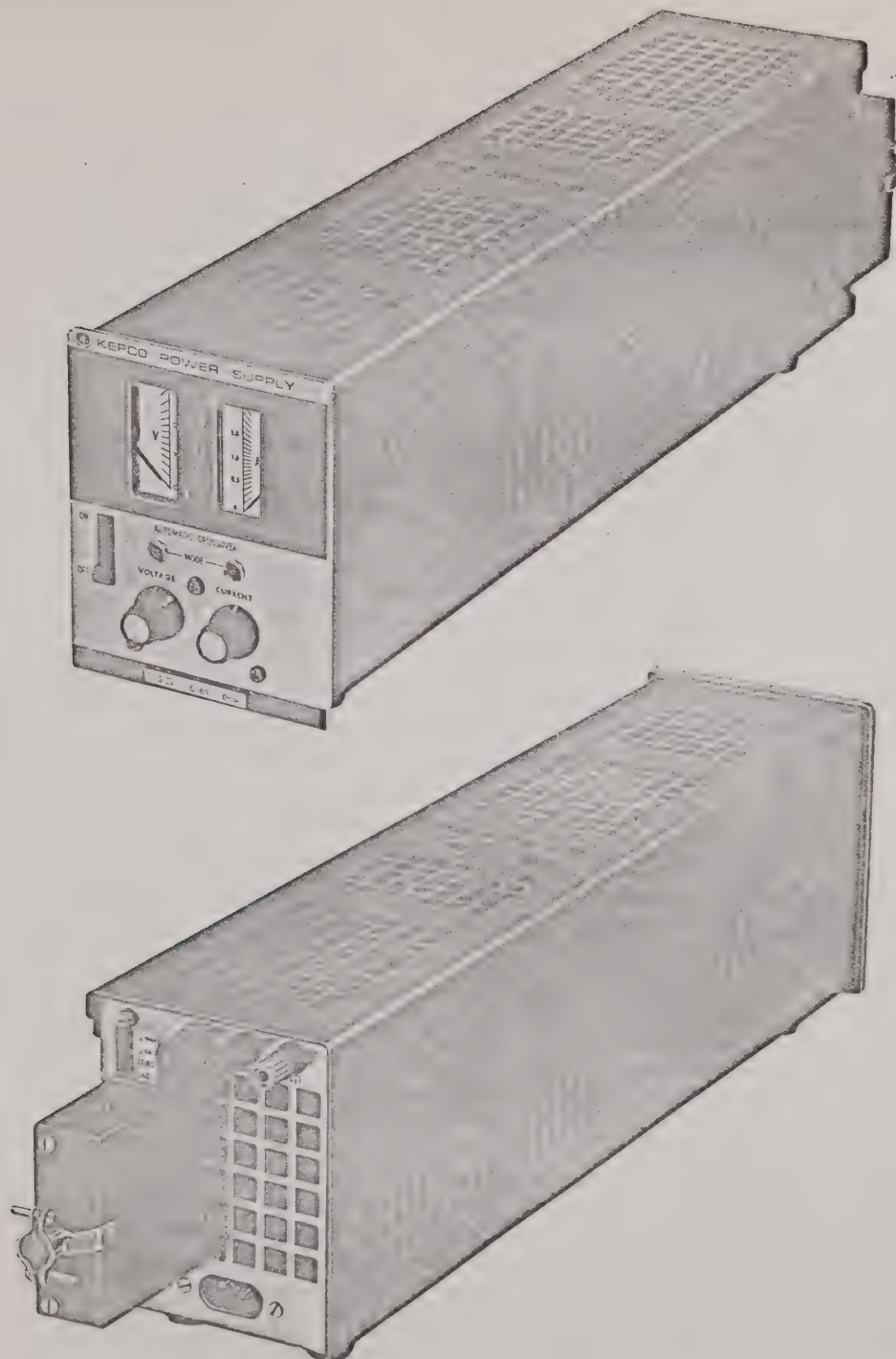


FIG. 1-1 OPS GROUPS IV, V OPERATIONAL POWER SUPPLY.
TYPICAL FRONT AND REAR VIEW.

SECTION I – INTRODUCTION

1-1 SCOPE OF MANUAL

- 1-2 This manual contains instructions for the installation, operation, and maintenance of the operational power supplies in the OPS GROUPS IV and V, manufactured by Kepco, Inc., Flushing, New York.

1-3 GENERAL DESCRIPTION (Refer to FIG. 1-1)

- 1-4 The Kepco OPS GROUPS IV and V consists of a series of two channel, wide-band operational power supplies which can be used for all applications requiring a fully programmable, wide-band, unipolar d-c amplifier.
- 1-5 The OPS is constructed in a "quarter-rack" package. (Four units fit side by side into a standard 19 inch rack.) All OPS GROUP IV and V models are identical in their mechanical dimensions. They are equipped with front panel meters and 10-turn precision rheostats for the (local) control of the output voltage and current. These controls can be disconnected at the rear programming connector and external controls can be substituted for remote output control. A circuit breaker and a pair of mode indicators (panel lamps, indicating whether the voltage or the current channel has control over the output) complete the front panel equipment of the OPS. The output is terminated at the rear via "5-way" binding posts. A-C source power connection is made with a detachable, 3-wire safety line cord. Programming connections are made at the rear programming connector (PC-4, supplied with OPS, wired for local control and sensing).
- 1-6 Some popular applications of the OPS are listed below:
- a) **Voltage Channel Programming.** (Current channel used as a front panel controlled current limiter.)
 - 1) High speed d-c voltage source. (Remote *or* local control.)
 - 2) Scaling or summing amplifier.
 - 3) Impedance transformer.
 - 4) Precision current source. (External Sensing and Control.)
 - b) **Current Channel Programming.** (Voltage channel used as a front panel controlled voltage limiter.)
 - 1) High speed d-c current source. (Remote *or* local control by potentiometer.)
 - 2) High speed d-c current source, remotely-controlled by signal voltage.

These, and other applications are fully described in Section III of this manual.

- 1-7 The OPS circuitry, in its simplest form, can be represented as shown in the fold-out diagram in Section IV of this manual. The POWER AMPLIFIER section consists of the raw d-c supply, in series with NPN silicon power transistors, mounted on a patented, highly efficient heat sink and cooled by a low noise, single bearing fan. The series power transistors are driven by a common DRIVER stage. The VOLTAGE-MODE amplifier and the two CURRENT-MODE amplifiers are integrated circuit "OP-AMPS," with very low offset errors. Each control amplifier is connected to the DRIVER via a diode "OR" gate, so that only one amplifier at a time controls the output. Amplifier input terminals are available on the REAR PROGRAMMING CONNECTOR, where the internal controls can be disconnected and where all other programming connections are made. As seen from the diagram, the VOLTAGE-MODE amplifier and the EXTERNAL CURRENT-MODE amplifier can be remotely controlled, while the INTERNAL CURRENT-MODE amplifier is permanently committed for its current limiting function. All control amplifiers are internally stabilized, permitting operation of the OPS without an output capacitor. The low shunt capacitance thus achieved allows for rapid voltage programming and fast recovery from the effect of step load changes.

1-8 SPECIFICATIONS, GENERAL (See also Table 1-1).

- SOURCE: 105 to 125V a-c or 210 to 250V a-c (selectable, refer to SECTION II), 50 to 65 Hz,* single phase. Refer to the Table of General Specifications (Table 1-1) for the a-c source current for each model.
- OPERATING TEMPERATURE RANGE: (-)20°C to (+)71°C (without derating of the output).
- STORAGE TEMPERATURE: (-)40°C to (+)85°C.
- COOLING: High efficiency, single bearing fan, (permanently lubricated) with special low noise nonmetal blade.
- ISOLATION: A maximum of 500 volts (d-c or p-p) can be connected between chassis and either output terminal. Common-mode current from output (either side) to ground: <5 μ A rms, 50 μ A p-p at 60 Hz.

*Consult factory for operation above 65 Hz.

MODEL	D-C OUTPUT RANGE		OUTPUT IMPEDANCE		SOURCE CURRENT AT 125 V A-C
	VOLTS	AMPS	VOLTAGE MODE D-C OHMS + SERIES L	CURRENT MODE ⁽¹⁾ D-C OHMS + SHUNT C	
OPS 6-5M	0-6	0-5	$60 \times 10^{-6} + 20 \mu\text{H}$	$0.2 \text{ M}\Omega + 5.0 \mu\text{F}$	1.4A
OPS 6-10M	0-6	0-10	$30 \times 10^{-6} + 50 \mu\text{H}$	$0.1 \text{ M}\Omega + 10.0 \mu\text{F}$	2.4A
OPS 15-3M	0-15	0-3	$250 \times 10^{-6} + 20 \mu\text{H}$	$0.33 \text{ M}\Omega + 3.0 \mu\text{F}$	1.4A
OPS 15-6M	0-15	0-6	$125 \times 10^{-6} + 50 \mu\text{H}$	$0.16 \text{ M}\Omega + 6.0 \mu\text{F}$	2.4A
OPS 25-2M	0-25	0-2	$625 \times 10^{-6} + 50 \mu\text{H}$	$0.5 \text{ M}\Omega + 2.0 \mu\text{F}$	1.4A
OPS 25-4M	0-25	0-4	$312 \times 10^{-6} + 50 \mu\text{H}$	$0.25 \text{ M}\Omega + 4.0 \mu\text{F}$	2.4A
OPS 36-1.5M	0-36	0-1.5	$1.2 \times 10^{-3} + 80 \mu\text{H}$	$0.67 \text{ M}\Omega + 1.5 \mu\text{F}$	1.4A
OPS 36-3M	0-36	0-3	$0.6 \times 10^{-3} + 50 \mu\text{H}$	$0.33 \text{ M}\Omega + 3.0 \mu\text{F}$	2.4A
OPS 55-1M	0-55	0-1	$2.75 \times 10^{-3} + 80 \mu\text{H}$	$1.0 \text{ M}\Omega + 1.0 \mu\text{F}$	1.4A
OPS 55-2M	0-55	0-2	$1.4 \times 10^{-3} + 80 \mu\text{H}$	$0.5 \text{ M}\Omega + 2.0 \mu\text{F}$	2.4A
OPS 75-0.75M	0-75	0-0.75	$5.4 \times 10^{-3} + 80 \mu\text{H}$	$1.3 \text{ M}\Omega + 0.75 \mu\text{F}$	1.4A
OPS 75-1.5M	0-75	0-1.5	$2.5 \times 10^{-3} + 80 \mu\text{H}$	$0.65 \text{ M}\Omega + 1.5 \mu\text{F}$	2.4A
OPS 100-0.5M	0-100	0-0.5	$10 \times 10^{-3} + 80 \mu\text{H}$	$2 \text{ M}\Omega + 0.5 \mu\text{F}$	1.4A
OPS 100-1M	0-100	0-1	$5 \times 10^{-3} + 80 \mu\text{H}$	$1 \text{ M}\Omega + 1.0 \mu\text{F}$	2.4A

⁽¹⁾ d-c value is for external sensing and feedback; d-c value for internal-sensing mode is $E_0/3 \text{ mA}$.

TABLE 1-1 GENERAL SPECIFICATIONS, OPS GROUPS IV, V.

1-9 SPECIFICATIONS, ELECTRICAL

a) OUTPUT EFFECTS: Refer to Table 1-2.

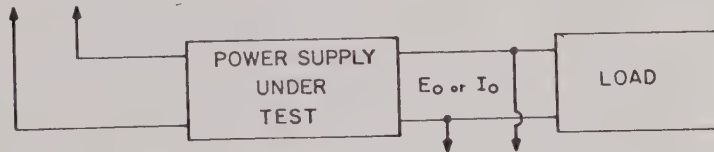
NOTE: In this instruction manual Kepco discontinues the use of the specifications entitled "line regulation" and "load regulation" because of the long standing (and misleading) connotation that a power supply regulates the line or the load. Instead, Kepco will follow the NEMA standards for D-C Power Supplies and speak of the "Output Effects," caused by changes in the "Influence Quantities." The "Output Effects" are specified either as a percentage change, referred to the maximum specified output voltage (E_o) or current (I_o), or as an absolute change (ΔE_o , ΔI_o), directly in millivolts or milliamperes of both.⁽¹⁾ The illustration below will clarify the new NEMA terms.

⁽¹⁾NOTE: The d-c performance of Operational Power Supplies is specified in terms of the OFFSET VOLTAGE and the OFFSET CURRENT at the input of the UNCOMMITTED CONTROL CHANNEL. The OUTPUT EFFECT for Operational Power Supplies can be calculated for each application. See Table 1-2, Note 4.

INFLUENCE QUANTITIES

- 1) SOURCE
- 2) LOAD
- 3) TEMPERATURE
- 4) TIME

A-C INPUT SOURCE (Formerly "A-C LINE")



OUTPUT EFFECTS (ΔE_o , ΔI_o)

- | | | |
|-----------------------|----------------------------------|--|
| 1) DUE TO SOURCE | = SOURCE EFFECT | (formerly LINE REGULATION) |
| 2) DUE TO LOAD | = LOAD EFFECT | (formerly LOAD REGULATION) |
| 3) DUE TO TEMPERATURE | = TEMPERATURE EFFECT COEFFICIENT | (formerly TEMPERATURE COEFFICIENT) |
| 4) DUE TO TIME | = DRIFT | (formerly STABILITY) |

INFLUENCE QUANTITIES	UNCOMMITTED CONTROL CHANNEL ⁽⁴⁾		CURRENT CONTROL CHANNEL OUTPUT EFFECTS
	OFFSET VOLTAGE ΔE_{io}	OFFSET CURRENT ΔI_{io}	
SOURCE: 105-125/210-250V a-c	$<5 \mu V$	$<1 \text{ nA}$	$<0.005\%$
LOAD: No load — full load.	$<100 \mu V^{(2)}$	$<5 \text{ nA}$	$<3.0 \text{ mA}$
TIME: 8-hour [drift]	$<20 \mu V$	$<1 \text{ nA}$	$<0.05\%$ or $0.1 \text{ mA}^{(1)}$
TEMPERATURE: Per °C	$<20 \mu V$	$<2 \text{ nA}$	$<0.05\%$ or $0.1 \text{ mA}^{(1)}$
UNPROGRAMMED OUTPUT DEVIATION ⁽³⁾ (Ripple and noise)	$<0.01\%$ of E_o max or $3 \text{ mV}^{(1)}$	$<0.01\%$ of I_o max or $3 \text{ mA}^{(1)}$	$<0.02\%$ or $0.5 \text{ mA}^{(1)}$
rms p-p 20 Hz — 10 MHz	$<0.05\%$ of E_o max or $10 \text{ mV}^{(1)}$	$<0.05\%$ of I_o max or $10 \text{ mA}^{(1)}$	$<0.08\%$ or $2 \text{ mA}^{(1)}$

⁽¹⁾ Whichever is greater.

⁽²⁾ ΔE_{io} for No Load to Full Load change in the current stabilization mode is equal to $\Delta E_o/10^6$, where ΔE_o is the compliance voltage change.

⁽³⁾ One terminal grounded or connected so that common-mode current does not flow through load or (in current mode) through a sensing resistor.

⁽⁴⁾ The amplifier offsets are given for the calculation of the output effects if the uncommitted control channel is used for operational programming. In this case, the value of the external feedback and input resistors, the amplifier offsets and the reference voltage variations are combined in the "Error Equation," which represents the "worst case" output effects for the application at hand:

$$\Delta E_o = \Delta E_{ref} (R_f/R_i) + \Delta E_{io} (1 + R_f/R_i) + \Delta I_{io} R_f$$

where: ΔE_o = Total Output Voltage Change
 ΔE_{ref} = Change in the Voltage Reference
 ΔE_{io} = Change in Offset Voltage
 ΔI_{io} = Change in Offset Current
 R_f = External Feedback Resistor
 R_i = External Input Resistor

NOTE: Variations in the value of the feedback and input resistors are considered secondary effects in the Error Equation.
 See Section IV of this manual for the derivation of the Error Equation.

TABLE 1-2 OPS GROUPS IV, V, ELECTRICAL SPECIFICATIONS.

- b) OUTPUT RANGES: (See Table 1-1 for specific rating by model number).
 - 1) VOLTAGE MODE: 0 to 100% of rated voltage.
 - 2) CURRENT MODE (INTERNAL SENSING AND CONTROL):
SETTING RANGE: 2% I_O max to 100% I_O max.
 - 3) CURRENT MODE (EXTERNAL SENSING AND CONTROL, 1-volt sample with current feedback to the *voltage* amplifier): Approximately 1 microampere to 100% I_O max.
- c) DYNAMICS (VOLTAGE CHANNEL):
 - 1) SLEWING RATE (Fastest rate of change obtainable): $>1 \times 10^6$ volts per second.
 - 2) PROGRAMMING TIME CONSTANT (Measured in the linear operating region as the exponential response to an input step function: The time to reach 63% of the rated output voltage.) The programming time constant is a measure of the OPS programming speed and is approximately equal to the selected RC product of the feedback resistance (1000 ohms per volt of output) and the feedback capacity (adjustable in the range from 800 to 1600 pF).
 - 3) LOAD REACTANCE: Maximum capacitive loading: 0.001 microfarad. For inductive loads, series diodes are required to protect the OPS from the back EMF generated by the load.
- d) DYNAMICS (CURRENT CHANNEL):
 - 1) CURRENT RECOVERY: The absence of a major shunt capacitance across the OPS GROUPS IV and V output terminals allows the load compliance voltage to follow a dynamic load at speeds up to the tabulated slewing rate. The recovery time (measured to the first time constant) is a function of the control circuit parameters. It is either governed by a circuit dependent RC time constant or it is rate limited by the current control setting, divided by the tabulated OPS output capacitance.

1-10 MISCELLANEOUS FEATURES

- a) CONTROL/PROGRAMMING
 - 1) VOLTAGE CHANNEL: Output voltage is controlled continuously throughout the range by a panel-mounted, 10-turn rheostat. External control can be exercised by resistance or by a control voltage. Control is fully operational, with OPS Power Supplies functioning as differential operational power amplifiers. Their plus error-sensing terminal is common.
 - 2) CURRENT CHANNEL (INTERNALLY SENSED): Output current is controlled continuously throughout the range by a panel-mounted, 10-turn potentiometer. External control of the internally-sensed current channel can be exercised by an external potentiometer or by a small control voltage. The plus (+) output terminal is the control signal return point (common). When controlling the internally-sensed current channel externally, the power supply's panel-mounted current control serves as an adjustable maximum current limit.
- b) MODE FLAG: A pair of panel lamps operate to indicate whether the voltage channel or the internally-sensed current channel is in control of the output. In addition, a d-c "flag" signal is provided: voltage mode flag is $\geq 5V$ d-c; current mode flag is $\leq 0V$ d-c referenced to the (+) OUTPUT terminal. Source impedance 5 k ohms.
- c) REMOTE ERROR SENSING: Separate voltage-sensing terminals permit 4-wire connections to a load. Remote error sensing compensates for static load effects up to 0.5V per lead.

1-11 ACCESSORIES (OPTIONAL, NOT SUPPLIED)

- 1-12 OPS models may be rack-mounted using the RA-32 Rack Adapter, which accepts (2) OPS units and (3) one-sixth rack modules or they may be installed into the Kepco RA-24 hardware system for "quarter-rack" units listed below:
 - a) RACK ADAPTER (FOR FOUR UNITS) KEPKO MODEL RA-24. Fits standard EIA rack dimensions. FILLER PANELS to cover empty slots if adapter is used for less than its capacity:
 - 1) KEPKO MODEL RFP 24-1, to cover (1) empty slot.
 - 2) KEPKO MODEL RFP 24-2, to cover (2) empty slots.
 - 3) KEPKO MODEL RFP 24-3, to cover (3) empty slots.
 - b) PROGRAMMING CONNECTOR, KEPKO MODEL PC -4. Note: One Model PC-4 is supplied, wired for standard operation (local control).

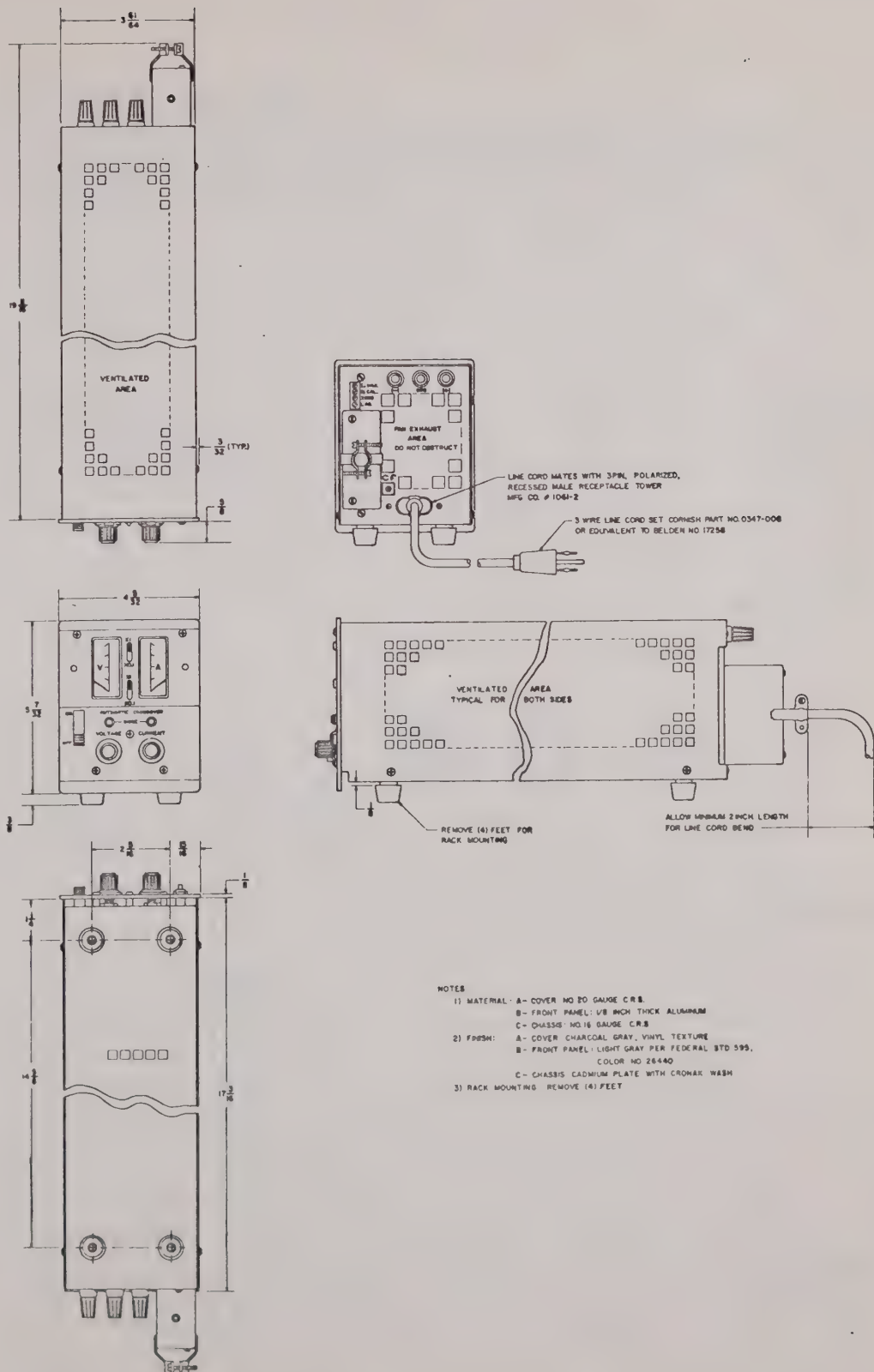


FIG. 1-2 MECHANICAL OUTLINE DRAWING.

SECTION II – INSTALLATION

2-1 UNPACKING AND INSPECTION

- 2-2 This instrument has been thoroughly inspected and tested prior to packing and is ready for operation. After careful unpacking, inspect for shipping damage before attempting to operate. Perform the preliminary operational check as outlined in par. 2-8 below. If any indication of damage is found, file an immediate claim with the responsible transport service.

2-3 TERMINATIONS

- FRONT PANEL: Refer to FIG. 2-2 and Table 2-2.
- REAR: Refer to FIG. 2-3 and Table 2-3.
- INTERNAL CALIBRATION CONTROLS: Refer to FIG. 2-1 and Table 2-1.

REFERENCE DESIGNATION	CONTROL	PURPOSE	ADJUSTMENT PROCEDURE
C14	C_f ADJUSTMENT	A-C STABILITY ADJUSTMENT	par. 3-18
R19	I_o MAX. ADJUSTMENT	MAXIMUM OUTPUT CURRENT ADJUSTMENT	par. 5-6
R30	I_b CAL. ADJUSTMENT	CONTROL CURRENT CALIBRATION	par. 3-15
R27	E_{io} NULL ADJUSTMENT	ZERO OUTPUT CALIBRATION	par. 3-15
R32	LAG ADJUST	A-C STABILITY ADJUSTMENT	par. 3-18

TABLE 2-1 INTERNAL ADJUSTMENTS AND CALIBRATIONS.

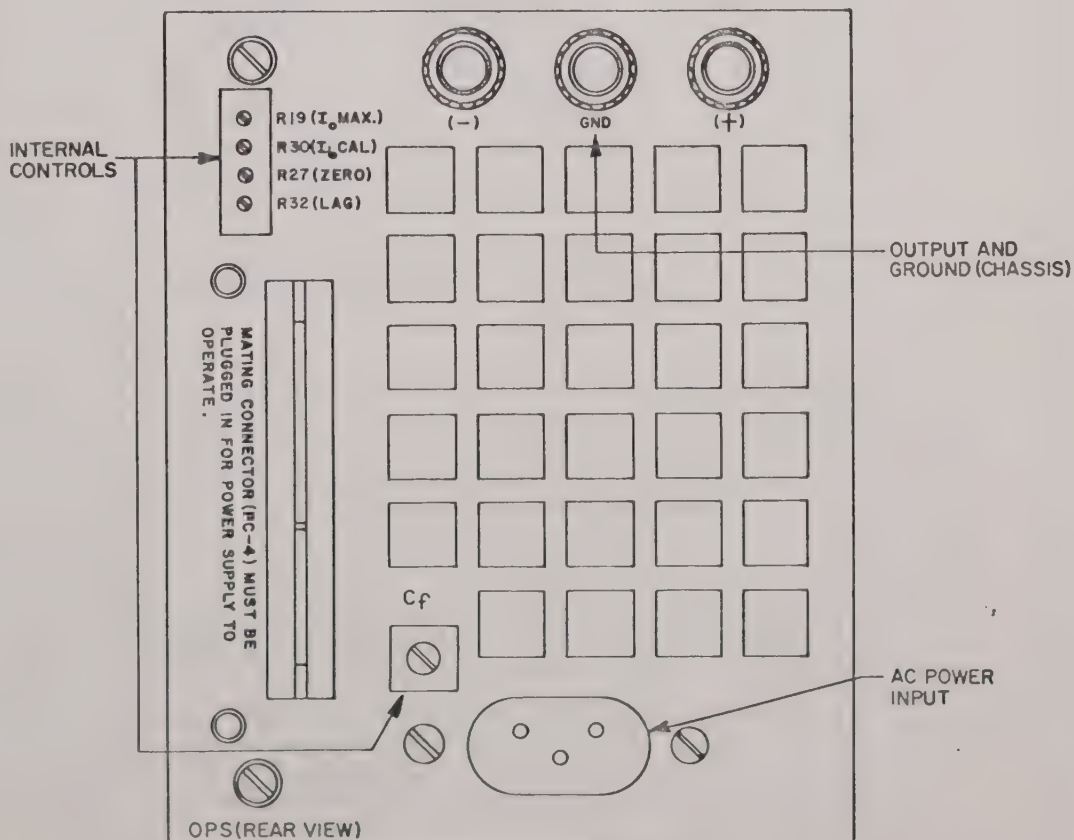


FIG. 2-1 LOCATION OF INTERNAL CONTROLS.

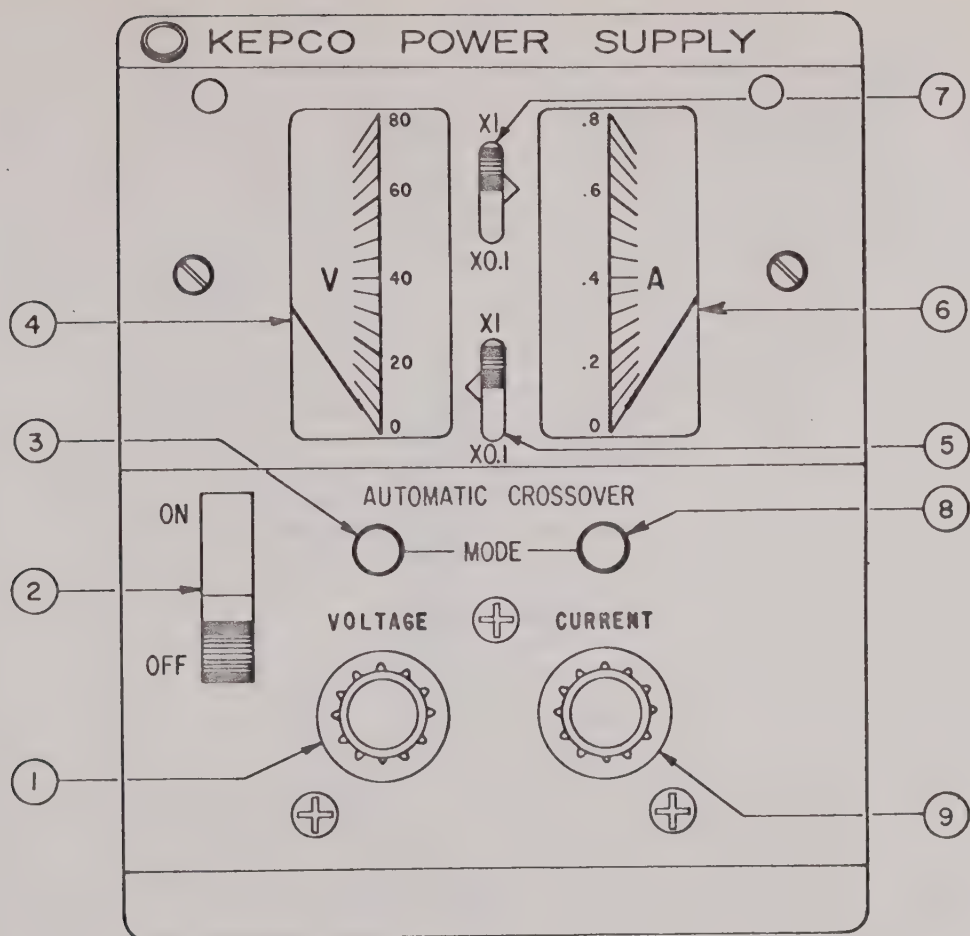


FIG. 2-2 CONTROLS AND TERMINATIONS, 1/4 RACK, OPS GROUPS IV, V, FRONT.

NO.	CONTROL OR TERMINATION	FUNCTION
1.	VOLTAGE CONTROL	ADJUSTS OUTPUT VOLTAGE FROM ZERO TO E_0 max.
2.	A-C POWER SWITCH/ CIRCUIT BREAKER	SERVES AS A-C POWER SWITCH AND TURNS A-C POWER LINE "OFF" ON OVERLOAD
3.	"V" MODE INDICATOR	ENERGIZES IN VOLTAGE MODE
4.	VOLTMETER	MONITORS OUTPUT VOLTAGE $0-E_0$ max. OR $0-E_0$ max./10
5.	VOLTMETER RANGE SWITCH	CHANGES METER RANGE FROM $0-E_0$ max. TO $0-E_0$ max./10
6.	AMMETER	MONITORS OUTPUT CURRENT $0-I_0$ max. OR $0-I_0$ max./10
7.	AMMETER RANGE SWITCH	CHANGES METER RANGE FROM $0-I_0$ max. TO $0-I_0$ max./10
8.	"I" MODE INDICATOR	ENERGIZES IN CURRENT MODE
9.	CURRENT CONTROL	ADJUST OUTPUT CURRENT FROM 2% TO 100% I_0 max.

TABLE 2-2 CONTROLS AND TERMINATIONS, OPS GROUPS IV, V.

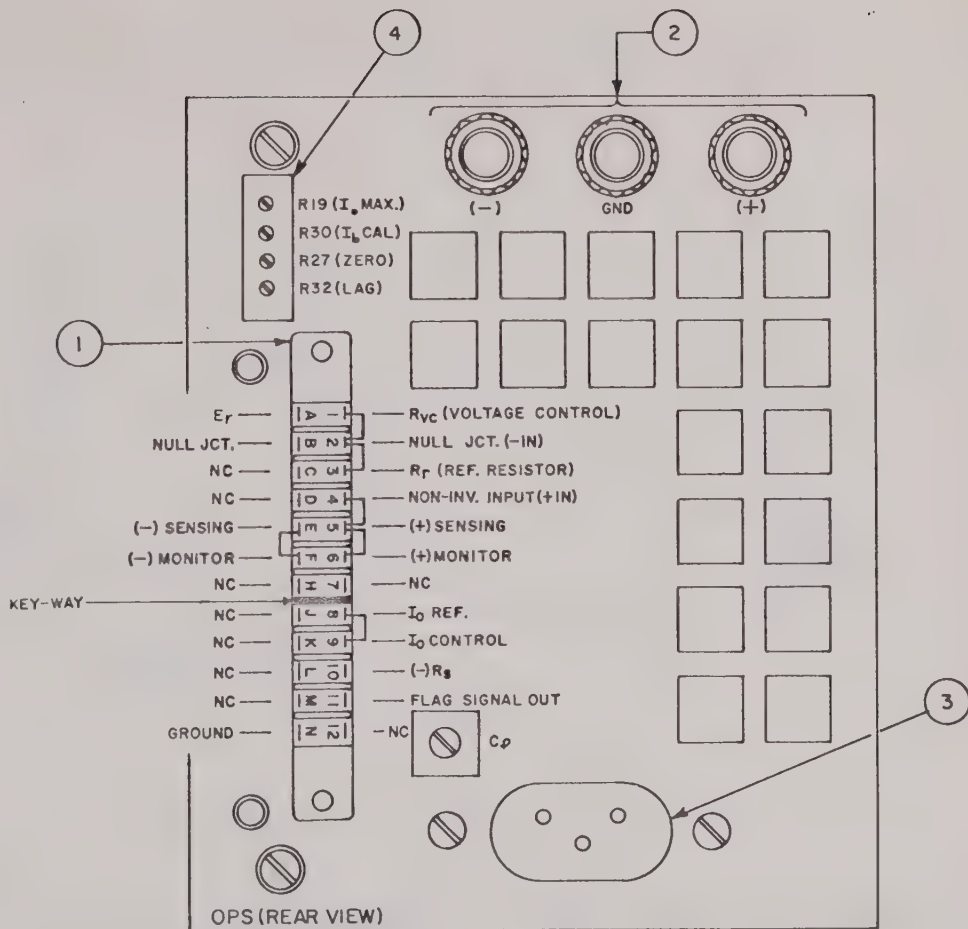


FIG. 2-3 TERMINATIONS, OPS GROUPS IV, V, REAR.

NO.	TERMINATION	FUNCTION
1.	REAR MATING CONNECTOR (PC-4) SHOWN ATTACHED TO REAR OF THE OPS.	FOR ERROR SENSING, EXTERNAL PROGRAMMING
2.	OUTPUT TERMINALS	{ (+) D-C OUTPUT (RED) (-) D-C OUTPUT (BLACK) GROUND (CHASSIS CONNECTION) GREEN }
3.	A-C POWER INPUT	ACCEPTS 3-WIRE A-C INPUT CORD (SUPPLIED)
4.	INTERNAL ADJUSTMENTS	CALIBRATION AND SETUP CONTROLS. (SEE TABLE 2-1.)

TABLE 2-3 REAR TERMINATIONS, OPS GROUPS IV, V.

2-4 A-C INPUT REQUIREMENTS

- 2-5 This power supply is normally supplied for operation on a single phase, nominal 115V a-c line. For conversion to 230V a-c line operation, refer to FIG. 2-4. Simply set the A-C SOURCE VOLTAGE SELECTOR switch to the "230" position. The circuit breaker (CB101) remains equally effective at *both* input voltages.

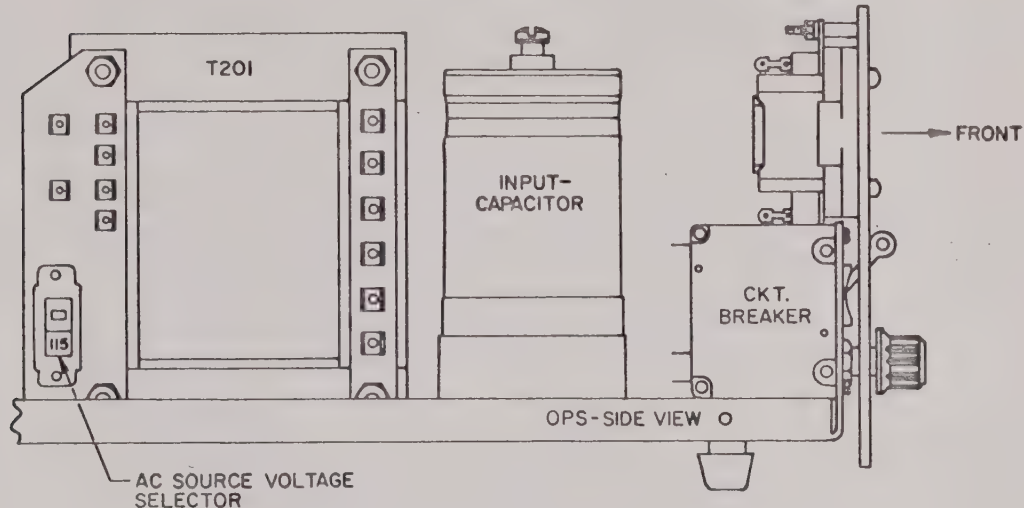


FIG. 2-4 CONVERSION FOR 230V A-C NOMINAL SOURCE.

2-6 COOLING

- 2-7 The power transistors and rectifiers in the power supply are maintained within their operating temperature range by means of a high-efficiency heat sink assembly, cooled by an internal fan. SIDE PANEL OPENINGS AND THE TOP OF THE CASE MUST BE KEPT CLEAR FROM OBSTRUCTIONS TO INSURE PROPER AIR CIRCULATION. Periodic cleaning of the interior of the power supply is recommended. If the power supply is rack-mounted, or installed into confined spaces, care must be taken that the ambient temperature (the temperature immediately surrounding the power supply) does not rise above the limit specified (71°C).

2-8 PRELIMINARY CHECKOUT

NOTE: THE REAR PROGRAMMING CONNECTOR (PC-4) MUST BE ATTACHED AND WIRED AS SHOWN IN FIG. 2-3.

- 2-9 A simple operating check, after unpacking and before permanent installation, is advisable to ascertain whether the power supply has suffered damage resulting from shipment. Refer to FIG. 2-2 and FIG. 2-3 for the location of the operation controls and output terminals.
- Connect power supply to 115V a-c source, or refer to par. 2-4 for 230V a-c operation, if required.
 - Turn CURRENT CONTROL fully clockwise. Turn VOLTAGE CONTROL fully counterclockwise. Both, VOLTMETER RANGE and AMMETER RANGE switch should be in the "x1" position.
 - Turn A-C POWER SWITCH/CIRCUIT BREAKER "on." The VOLTAGE-MODE indicator lamp should be energized. Slowly turn VOLTAGE CONTROL clockwise and observe the gradual increase of the output voltage. Turn counterclockwise again, until about one-tenth of the maximum output voltage is reached. Set VOLTMETER RANGE switch to the "x0.1" position. The VOLTMETER should now read full scale again. Return both, AMMETER and VOLTMETER RANGE SWITCHES to the "x1" position.

- d) Place a short circuit across the output. Turn CURRENT CONTROL counterclockwise. Turn "on." THE CURRENT-MODE indicator lamp should be energized. Slowly turn CURRENT CONTROL clockwise and observe the gradual increase in output current. Turn counterclockwise until about one-tenth of the maximum output current is reached. Set AMMETER RANGE switch to the "x0.1" position. The AMMETER should now read full scale again.



Do not switch the "x0.1" ranges before the output of the power supply (voltage or current) is below 10% of the maximum rated values. Return both RANGE switches to the "x1" position.

2-10 INSTALLATION (Refer to FIG. 1-2 "Mechanical Outline Drawing")

- 2-11 The OPS Power Supply may be rack-mounted or operated as a "bench-type" instrument. If the OPS is to be rack-mounted, the (4) bottom feet must be removed.
- 2-12 The OPS Power Supply can be directly chassis-mounted into any system. Four nylon mounting standoffs are provided at the bottom of the unit. If no additional mechanical support is provided, the unit must always be mounted so that its weight rests on the four mounting standoffs.
- 2-13 For all installations into confined spaces, care must be taken that the temperature *immediately surrounding the unit* does not exceed the maximum specified ambient temperature (71°C).

2-14 GROUNDING

- a) A-C (SAFETY) GROUND. The power supply is equipped with a 3-wire safety line cord and polarized plug. The third (green) wire in the line cord is connected to the chassis and the case of the unit. If a 2-terminal receptacle in combination with an adapter is used, it is imperative that the chassis of the power supply be returned to a-c ground with a separate lead. A grounding terminal (green) is provided (at the rear of the chassis) for this purpose.
- b) D-C (SIGNAL) GROUND. The d-c output is isolated from the a-c source and from any *direct* connection to chassis or ground. The maximum output voltage that can be supported between either output terminal and ground or chassis is 500V d-c plus the maximum output voltage of the power supply. Either the positive *or* the negative side of the output must be signal-grounded, so that the common-mode current does not flow through the load or through an external sensing resistor. The specifications for the unprogrammed output deviations (ripple and noise) are valid only if one side of the output is signal grounded. See Section III (par. 3-5d) for more information on signal grounding.

SECTION III – OPERATION

3-1 INTRODUCTION

- 3-2 The operational power supplies in Kepco's OPS GROUPS IV and V are multifunction instruments, which can be used in a great variety of operating modes. As a PRECISION, HIGH SPEED VOLTAGE SOURCE, the output may be controlled by varying the feedback resistance (built-in VOLTAGE CONTROL or remote control by an external feedback resistor), by conductance (varying the control current by changing the input resistance), or by digital input signals, using one of Kepco's Digital Programming devices. The current control channel serves as a current limiter and may be independently controlled by means of the built-in CURRENT CONTROL, by remote potentiometer or by an external control voltage.
- 3-3 As a UNIPOLAR WIDE-BAND AMPLIFIER, the output of the OPS will respond to input sources such as sine, triangular or square-wave generators. The built-in VOLTAGE CONTROL may be used as a gain control, while the current control channel of the OPS may be used to limit the output current either remotely or by means of the front panel CURRENT CONTROL.
- 3-4 The current control channel may be used to operate the OPS as a continuously adjustable or dynamically programmable CURRENT SOURCE. In this mode of operation, the voltage channel serves as a voltage limiter, either locally controlled by means of the built-in VOLTAGE CONTROL, or remotely controlled using external resistance or voltage signals.
- 3-5 Detailed examples for various operating modes are given in the following paragraphs. Before actual operation, however, the following general comments on operational power supply programming should be considered:
- DIAGRAMS. Applications and setup diagrams in this section show the (simplified) equivalent diagram of the OPS GROUPS IV and V operational power supply circuit. The indicated terminations correspond with the actual pin numbers on the rear programming connector (PC-4), (refer to FIG. 3-1).

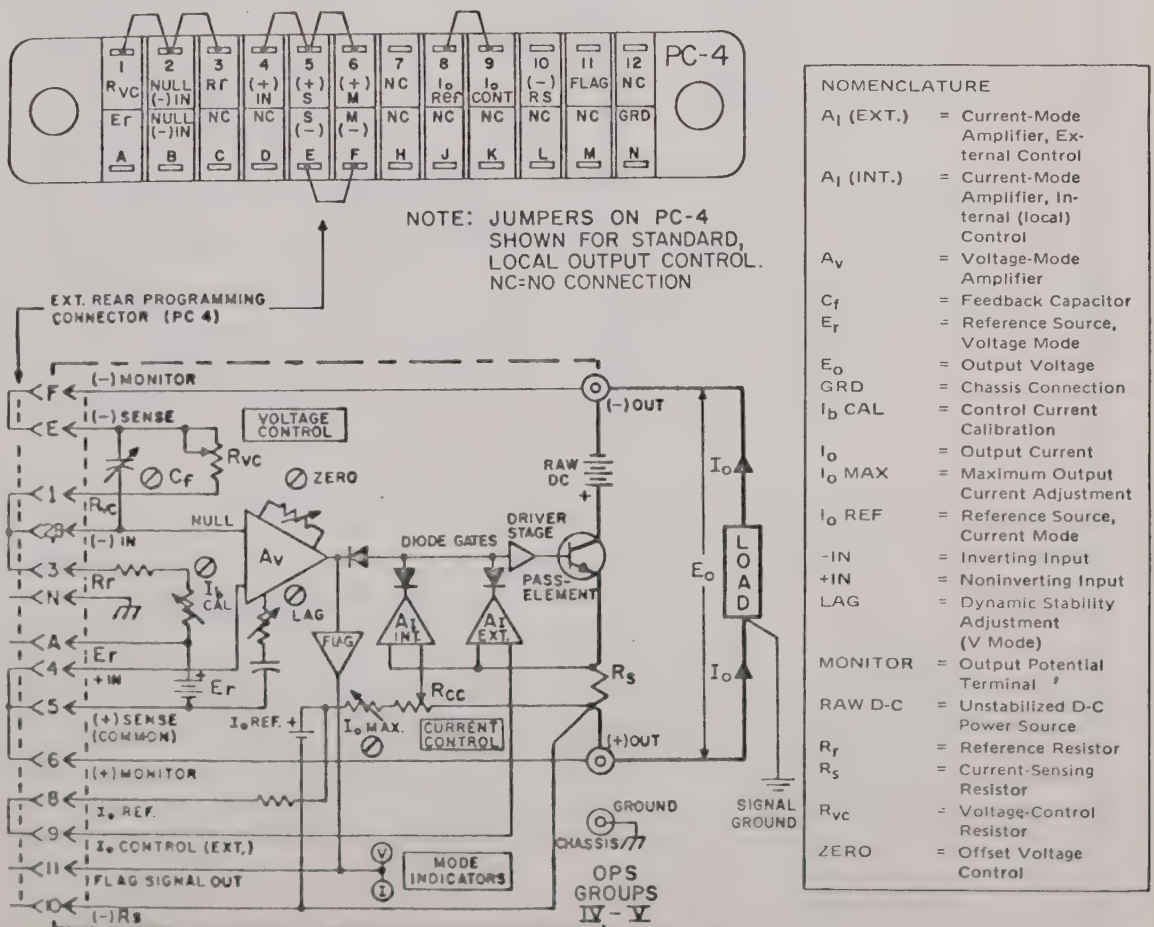


FIG. 3-1 OPS, SIMPLIFIED DIAGRAM.

- b) **LOAD CONNECTION (I).** The basic interconnection between the OPS and the load are shown in FIG. 3-1. The load wire size for the 2-wire connection shown should be as large as practicable to keep the series resistance and inductance low. In addition, the load wire pair should be tightly twisted, to reduce possible "pick-up" from stray magnetic fields. This connection is useful only where the voltage drop in the load wires is of minor consequence, as for example, operation into a constant load or in a constant current operating mode.
- c) **LOAD CONNECTION (II).** The recommended load connection for all applications requiring minimum output effects across a remote load is shown in FIG. 3-2. A twisted, shielded pair of wires (NO. 20 AWG minimum) are connected from the OPS "± sensing" terminals to the load. (For many applications twisted pair unshielded wire is adequate.) This "remote error sensing" technique will compensate for load wire voltage drops up to 0.5 volts per wire. **NOTE: OBSERVE POLARITIES: THE *NEGATIVE* SENSING WIRE MUST GO TO THE *NEGATIVE* LOAD WIRE. THE *POSITIVE* SENSING WIRE MUST GO TO THE *POSITIVE* LOAD WIRE.**

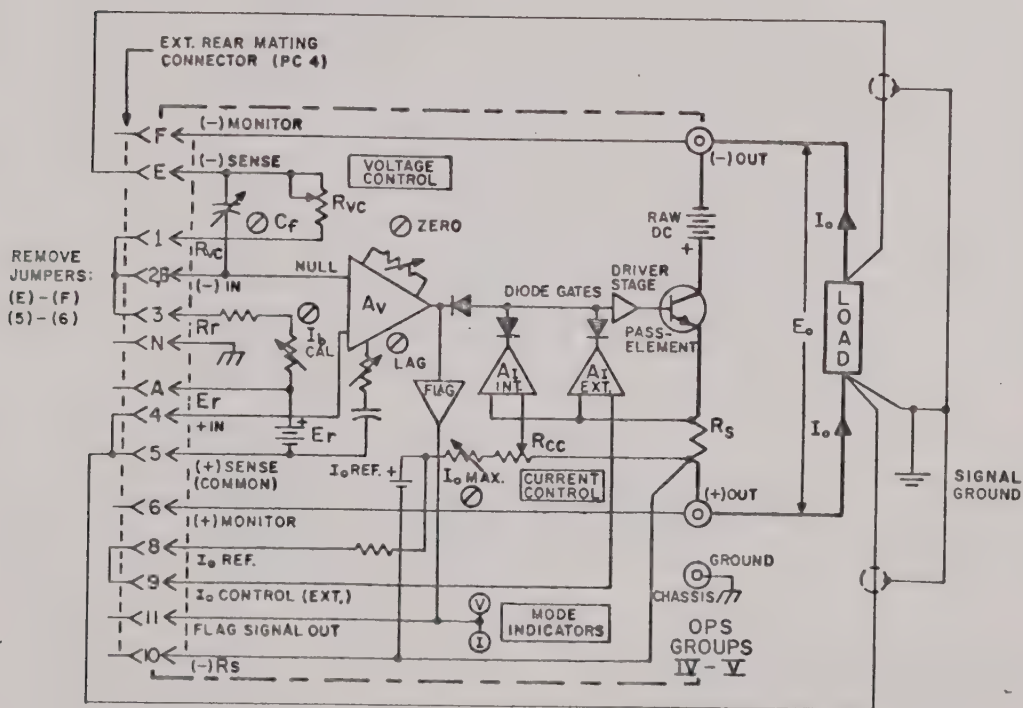


FIG. 3-2 REMOTE ERROR SENSING.

d) **GROUNDING**

- 1) A-C (SAFETY) GROUND (See Section II, par. 2-14).
- 2) D-C (SIGNAL) GROUND. Specified ripple and noise figures for operational power supplies are valid *only* with one side of the output/load circuit returned to a common ground point. (Refer to Section I, Table 1-2.) The *positive* side of the OPS output is shown grounded in all application diagrams, since it is "common" to both, internal reference source and any external signal input source. If the application requires, the negative side of the OPS output may be signal-grounded or the OPS output may be left ungrounded (floating). In the latter case, however, the ripple and noise level will increase somewhat, since the common-mode current (specified in Section I, par. 1-8e) flows now through the load (Voltage Mode) or through the sensing resistor (Current Mode). The signal ground point in the OPS/load circuit must consist of a *single point* only, to which all input source grounds, shields and load grounds are connected. Multiple signal grounds in the OPS output/load circuit cause "ground-loop" problems, since noise signals develop across the impedances between the multiple ground points. The exact physical location of the "best" single ground point must be carefully selected for minimum ripple/noise output.

- e) **EXTERNAL PROGRAMMING RESISTORS.** External programming resistors should be high-quality units, with low-temperature coefficients. Resistors should be selected carefully, since in most applications, the limitations for stability and drift are due not to the OPS, but to the programming resistors. Selection criteria for resistors are (in order of importance):

- 1) TEMPERATURE COEFFICIENT
- 2) INDUCTANCE
- 3) HUMIDITY EFFECTS
- 4) DRIFT WITH TIME
- 5) SELF-HEATING
- 6) TOLERANCE

For variable resistors (potentiometers or rheostats) similar selection criteria apply. In addition, such specifications as listed below should be carefully considered if the application requires:

- 1) END RESISTANCE
- 2) LINEARITY
- 3) CAPACITIVE AND INDUCTIVE EFFECTS

- f) **ACTIVE PROGRAMMING SOURCES.** External programming sources (Signal Generators, etc.,) or reference sources should have temperature coefficients and drift specifications comparable to (or better than) the OPS Power Supply. CAUTION: A-C connected programming sources must have their output isolated from the case. Older signal generators which do not have isolated outputs, can only be used if their *negative* output is tied to the case and can be connected to the OPS "common."
- g) **EXTERNAL SWITCHES.** Switch devices, used with multiple feedback resistors for step-voltage or current programming of the OPS, must be of the "make before break" type to avoid opening the feedback loop during switching. A momentarily open feedback loop causes large output excursions, since the control circuitry will try to respond to an open (infinite) feedback resistance.
- h) **EXTERNAL LEADS.** Shielded (preferably twisted) lead pairs are recommended for all input connections to the OPS control channels. The shield should be connected (single-ended) to the chosen signal ground point. Shielded leads should be held as short as practicable.

3-6 OPS OPERATION WITH LOCAL (FRONT PANEL) OUTPUT CONTROL

- 3-7 The OPS may be used as a fast responding d-c voltage or current source with the output adjusted by the front panel controls and with automatic "crossover" from the voltage to the current mode of operation. The crossover point and the operating mode is determined by the value of the load resistance (R_L) and the settings for the output voltage (E_O) on the VOLTAGE control and the output current (I_O) on the CURRENT control:

$$R_L = E_O / I_O, \text{ where: } R_L = \text{Load Resistance}$$
$$E_O = \text{Output Setting via VOLTAGE Control}$$
$$I_O = \text{Output Setting via CURRENT Control}$$

- 3-8 For load resistances *greater* than R_L , the OPS will operate in the *voltage mode* and the VOLTAGE mode indicator will be energized. For load resistances *smaller* than R_L , the OPS will operate in the *current mode* and the CURRENT mode indicator will be energized. Simultaneously with the front panel "MODE" indicator lamps, a "flag" signal is available at the rear programming connector (PC-4, pin 11 with reference to pin 5) signaling the mode crossover for use with external indicating devices.
- 3-9 When operating in the VOLTAGE mode, the OPS delivers stabilized d-c output voltage (combined SOURCE/LOAD effect $<0.01\%$ of rated output voltage) into the connected load. The VOLTAGE control in this mode of operation is set to the desired output voltage while the CURRENT control is set to the required maximum load current. The current channel of the OPS functions now as a current limiter: If the set current value is exceeded (shorted load circuit for example) the OPS transfers into the CURRENT mode.
- 3-10 When operating in the CURRENT mode, the OPS delivers stabilized output current (SOURCE effect 0.005% of I_O max; LOAD effect <3 milliamperes) into the connected load. The CURRENT control in this mode of operation is set to the desired output current, while the VOLTAGE control is set to the maximum compliance voltage required by the load. The VOLTAGE control functions now as a voltage limiter: If the set voltage is exceeded (open load circuit for example), the OPS transfers into the VOLTAGE mode.

PROGRAMMING THE OPS VOLTAGE CONTROL CHANNEL

3-11 REMOTE OUTPUT VOLTAGE CONTROL BY RESISTANCE

3-12 GENERAL. To control the output voltage of the OPS by a remote resistance, the internal VOLTAGE CONTROL must be disconnected at the rear programming connector and an external control resistor (R_{VC}) substituted (refer to FIG. 3-3). Using the built-in reference source of the OPS (E_r), which in series with the internal reference resistor (R_r), and a calibrating rheostat (I_b CAL), provides the necessary control current (I_b), each kilohm of programming resistance (R_{VC}) produces one volt of output (E_o) according to the "programming equation:"

$$E_o = E_r / R_r (R_{VC}), \quad (\text{Eq. 1}), \quad \text{where: } \begin{aligned} E_o &= \text{Output Voltage} \\ E_r &= \text{Reference Voltage} \\ R_r &= \text{Reference Resistance} \\ R_{VC} &= \text{Voltage Control Resistance} \end{aligned}$$

3-13 The ratio E_r/R_r in the given equation (Eq. 1) is equal to the control current I_b , since I_b is indeed derived from the internal reference voltage (E_r) in series with the internal reference resistor (R_r), so that $E_r/R_r = I_b$ (Eq. 2), and the programming equation (Eq. 1) may be simplified to:

$$E_o = I_b R_{VC} \quad (\text{Eq. 3}).$$

These equations (Eq. 1, 2, 3) may be used conveniently for all calculations involving component selection. They are derived in Section IV of this manual.

3-14 COMPONENT SELECTION. The external voltage control resistor (R_{VC}) should be chosen with care (refer to par. 3-5e). It may be in the form of a servo-driven or manually-operated rheostat as shown in FIG. 3-3, or it may consist of a precision resistor decade, or a relay-controlled step-switch arrangement, or digital control resistor such as Kepco DPR. The value for R_{VC} is based on the programming equation (Eq. 3): $E_o = I_b R_{VC}$. Since the internal control current (I_b) is equal to 1 milliampere, the "programming ratio" is 1000 ohms per volt, i.e., for each 1000 ohms of R_{VC} , 1 volt output is produced by the OPS.

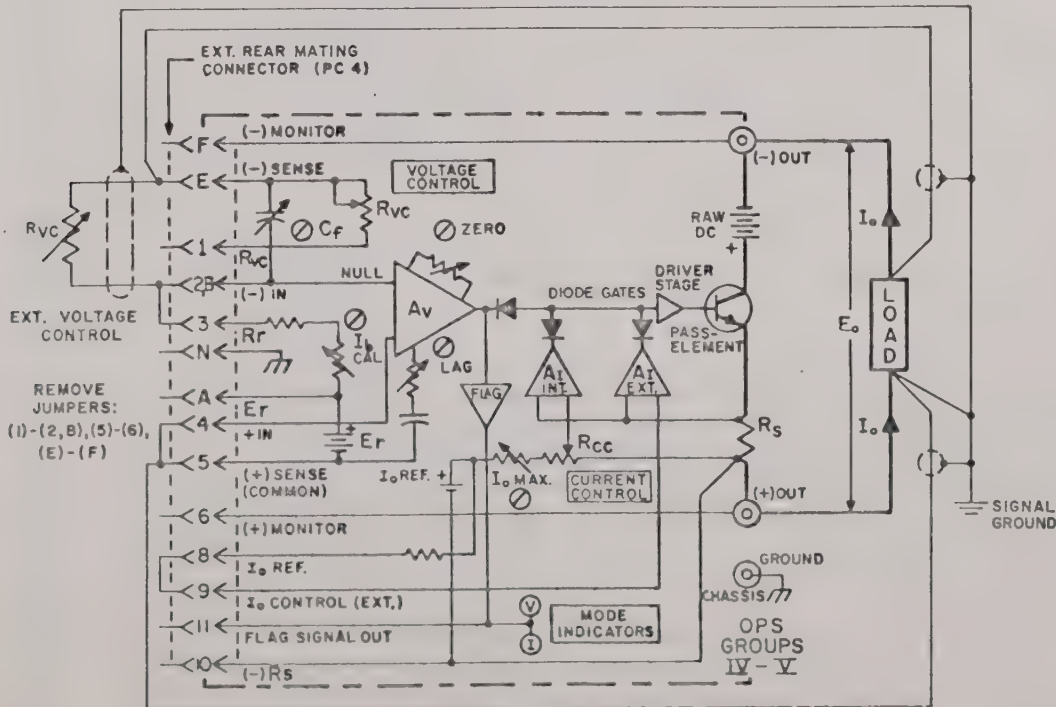


FIG. 3-3 REMOTE OUTPUT VOLTAGE CONTROL BY RESISTANCE.

3-15 CALIBRATION OF THE PROGRAMMING CIRCUIT. A precise 1000 ohm/volt programming ratio may be adjusted by following the procedure below:

3-16 CALIBRATION PROCEDURE

- Set up the calibration circuit as shown in FIG. 3-4. The required external components are listed below:
 - DIFFERENTIAL VOLTMETER, or Digital Voltmeter (M1).
 - SINGLE-POLE-SWITCH (S1).
 - PRECISION RESISTOR (R_{VC}). Note: Absolute value is not important, but must be *known*: For each ohm, 1 millivolt will appear at the output (with $I_b = 1.0$ mA). Accuracy: As required by your application.
 - CAPACITOR, Mylar, 0.1 microfarad – 200 volts (C_f).

NOTE: ALL CALIBRATION CONTROLS ARE ACCESSIBLE THROUGH THE REAR COVER OF THE OPS. (REFER TO SECTION II, FIG. 2-1.)

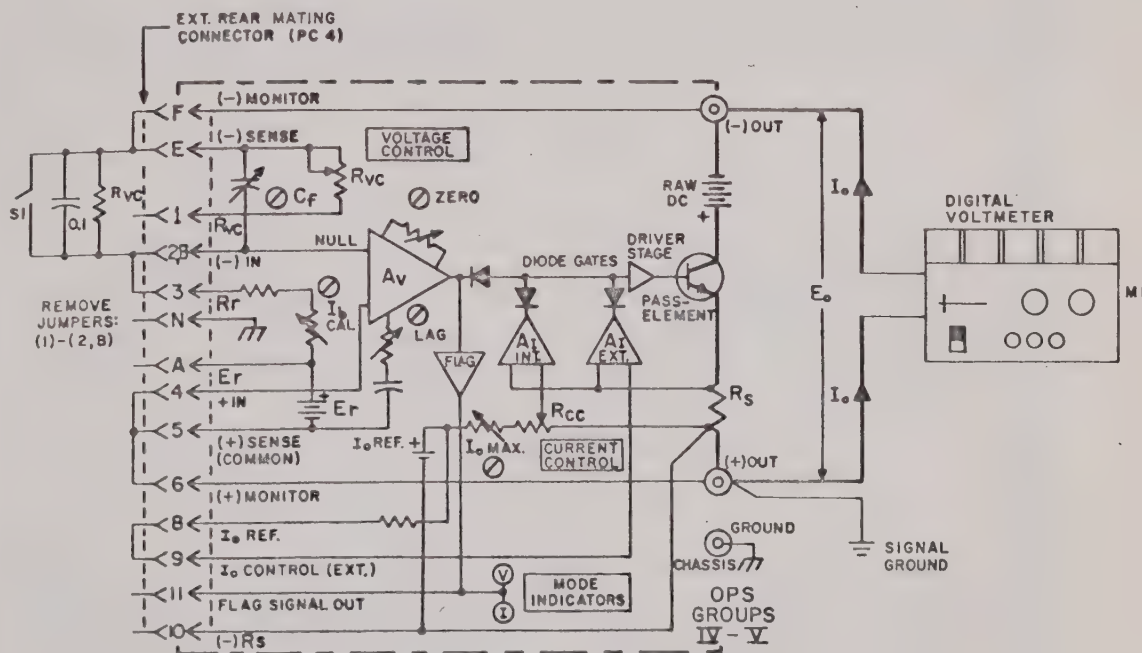


FIG. 3-4 CALIBRATING THE PROGRAMMING RATIO.

- ZERO CALIBRATION:**
Close S1. Turn A-C POWER "on." Adjust ZERO control until the voltmeter (M1) reads exactly zero volts.
 - I_b CALIBRATION:**
Open S1. The output voltage on the voltmeter should read exactly 1 millipere times the value of R_{VC} in kilohms. Adjust the internal I_b CAL control until this value is read-out on M1.
 - Repeat adjustments described in "b" and "c" as necessary, since a shift in the adjustments may take place during the time the OPS (and the voltmeter) reach thermal equilibrium. Turn a-c power "off."
 - Remove the calibration components. Connect external voltage control resistance and load.
- 3-17 SETTING THE OUTPUT CURRENT CONTROL. The front panel OUTPUT CURRENT control may be used as a current limiter by setting it to a value just beyond the anticipated load current. If the adjusted current value is exceeded, the OPS will transfer into the current mode, as indicated by the "I" mode indicator on the front panel. Proceed as follows:
- Turn a-c power "off," and turn CURRENT control counterclockwise.
 - Use the front panel ammeter ($\pm 3\%$ Accuracy) or connect a precision ammeter with the appropriate current range across the output terminals of the OPS.
 - Turn a-c power "on," and turn CURRENT control to the desired value. Turn a-c power "off," and reconnect the load.

NOTE: The output current-limit point may also be controlled remotely, see par. 3-48.

3-18 DYNAMIC STABILITY

3-19 GENERAL. The uncommitted channel of the OPS, when committed for voltage amplification or high speed resistance programming, represents an amplifying device with a relatively large bandwidth. Such devices are susceptible to the effects of load reactance, particularly capacitive reactance. The OPS is compensated for a controlled "rolloff" and phase shift. In order to maintain this controlled rolloff, it is necessary to confine the loading of the OPS to loads with nearly resistive properties. Excessive load reactance, and/or input capacitance in combination with certain feedback impedances, may give rise to "ringing," or "overshoot," or "oscillation" at the output of the OPS. Internal controls are provided in the OPS to compensate for a small range of load and input conditions. A lag network at the input of the uncommitted channel and an adjustable trimmer capacitor across the feedback terminals of the OPS may be individually adjusted for each load condition. These adjustments are accessible through the OPS rear cover and are marked LAG and C_f respectively. (Refer to Section II, FIG. 2-1 for location.)

3-20 ADJUSTMENTS. The dynamic characteristics of the OPS are optimized at the factory as follows:
The uncommitted channel is programmed with a square wave to its maximum power output into a resistive load. The OPS output is observed with a high-speed oscilloscope and the waveshape of the output square wave is optimized using the provided controls. (See illustration below.)

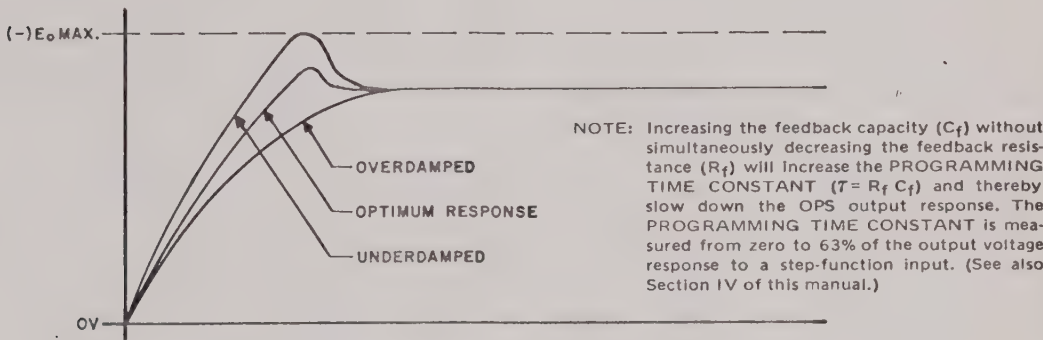


FIG. 3-5 OPS OUTPUT RESPONSE TO A (100 HZ) SQUARE-WAVE INPUT.

3-21 In cases of persistent dynamic instability (oscillation) at the output of the OPS, the LAG and C_f controls should be *readjusted* for the conditions of the particular application. In some cases, an additional capacitor across the feedback terminals (2, B) – (E) will establish stability, at the cost of reduced bandwidth (i.e., programming speed). Investigate the load for excessive capacitance. Greater than specified load capacitances may introduce additional phase shift and the OPS may become unstable, especially with "follower" or "inverter" connections. The adjustment of the internal LAG and C_f controls in these cases may not help and may make the situation worse by increasing the net lag. (Consult factory for unusual load.)

3-22 LOADS WITH EXCESSIVE CAPACITANCE. The only solution, if such loads must be driven at higher frequencies, is to isolate them from the point at which the feedback is derived. (See illustration below.)

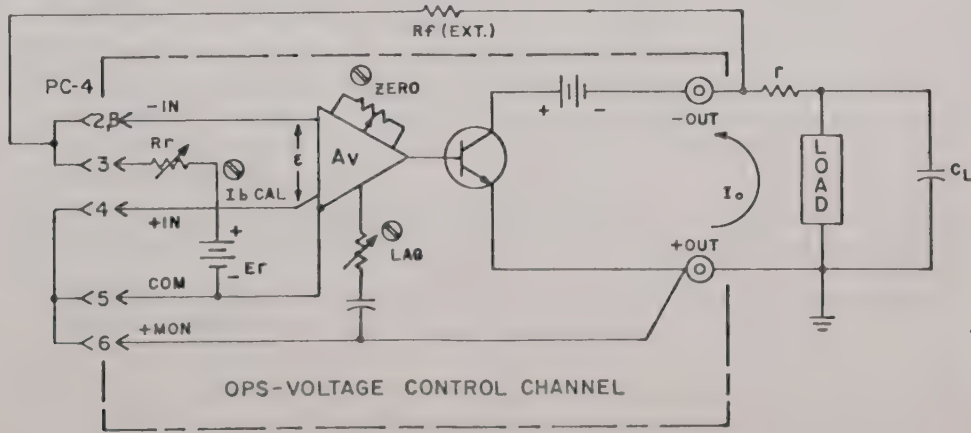


FIG. 3-6 ISOLATING A LOAD WITH EXCESSIVE CAPACITANCE.

- 3-23 The isolating resistor (r) should be only as large as is necessary to achieve stability, since the output impedance, is of course, increased by the amount of (r).
- 3-24 **OUTPUT VOLTAGE CONTROL BY EXTERNAL SIGNAL VOLTAGE.** In this application, the OPS functions as a unipolar power amplifier. The maximum peak-to-peak amplitude of the individual OPS model is equal to its rated d-c voltage output, and the average sine-wave power into a resistive load is one-quarter of the rated d-c voltage times the ampere product. The maximum, full power sine-wave frequency is approximately given by:

$$f_{\max} = \frac{\text{S.R.}}{\pi E_o \max}$$

where "S.R." is the slewing rate specified for the individual OPS model and " $E_o \max$ " is its rated maximum output voltage. For *bipolar* input waveforms, the OPS, being a *unipolar* device, must be biased to accommodate the output swing. If this were not done, the OPS would reproduce only the *negative*-going part of a bipolar input waveform. (Refer to FIG. 3-7.)

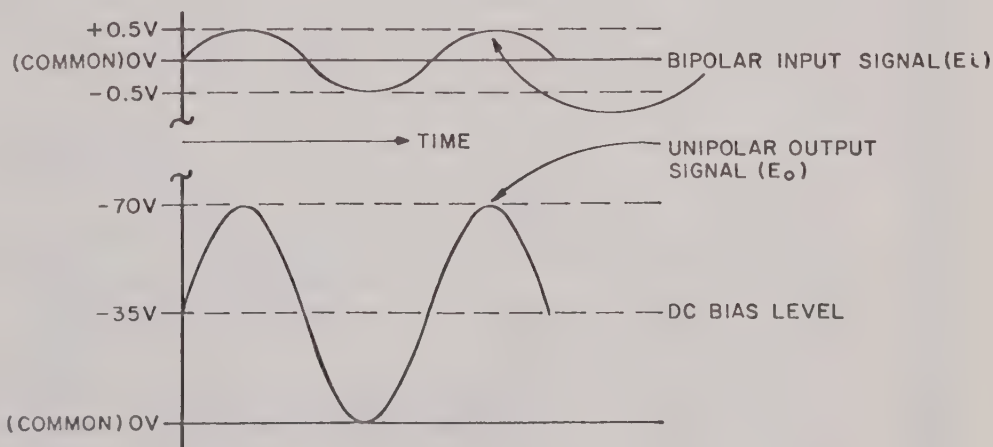


FIG. 3-7 INPUT/OUTPUT WAVEFORMS AND D-C BIAS.

- 3-25 **COMPONENT SELECTION.** Selection of external feedback and input resistors is based on the characteristics of the input source and on the desired circuit gain. The following examples will demonstrate component selection using various input sources and specific OPS models.
- 3-26 **EXAMPLE 1.** A Model OPS 75-1.5M is to be programmed from a bipolar sine-wave signal-generator able to provide 1 volt peak-to-peak into 600 ohms. An output amplitude of 70 volts is required.
- 3-27 Since the output signal is bipolar, the d-c output voltage level of the OPS is set to the middle of its d-c output range (≈ 35 volts), so that the amplified input signal will be totally confined to the OPS output range: It will start from (-) 35 volts, go to (-) 70 volts, return to (-) 35 volts and go to 0 volt and so on. (Refer to FIG. 3-7.) The resulting output waveform will be modulated d-c and will be unipolar, i.e., varying in *one* direction from zero.
- 3-28 The necessary d-c bias (-35 volts) at the OPS output is provided by setting the OPS VOLTAGE control to this value. Now, the a-c input signal is applied to the "inverting" input of the voltage-channel amplifier.
- 3-29 Since the sine-wave amplitude is to be 70 volts peak-to-peak, the a-c conditions are as follows:
- $E_o \text{ (a-c)} = 70\text{V (p-p)}$
 - $E_i = 1\text{V (p-p)}$
 - $R_f = 35\text{ k ohms}$
- NOTE: The front panel VOLTAGE control is used for " R_f ." If " R_f " is set for 35 volts, its value, at the internal programming ratio of 1000 ohms/volt is equal to 35 k ohms.

- 3-30 The necessary gain (E_o/E_i) is therefore 70. Since the operational gain of the inverting input circuit used can also be expressed by the ratio of the feedback resistor (R_f) and the input resistor (R_i), the latter value can be calculated by: $R_i = 35 \text{ k ohms}/70 = 500 \text{ ohms}$.
- 3-31 CALIBRATION. (Refer to Section II, FIG. 2-1 for location of controls.) Connect all external components as shown in FIG. 3-8. Connect an oscilloscope across the load. Turn OPS "on," and set output to zero by shorting the feedback terminals (2, B) – (E). Set to exact "zero" by means of the ZERO control. Remove short, set OPS VOLTAGE control to (-) 35 volts. Turn SIGNAL GENERATOR "on" and adjust amplitude to 1 volt peak-to-peak. Observe output wave with an oscilloscope. The amplified sine wave should have an amplitude from 0 to (-) 70 volts, as the input signal is varied from (-) 0.5 volt to (+) 0.5 volt. The full power frequency response of the OPS under these operating conditions will be approximately from d-c to $f_{\max}$, where:

$$f_{\max} = \frac{\text{Slewing Rate}}{\pi E_o \max} = \frac{1 \times 10^6}{6.28 (70)} \approx 2.3 \text{ kHz.}$$

NOTE: Increasing the input frequency above $f_{\max}$ will result in amplitude reduction and slope distortion.

- 3-32 As in any application, the front panel CURRENT control of the OPS should be set to the desired output current value. Refer to par. 3-17 for the adjustment procedure.

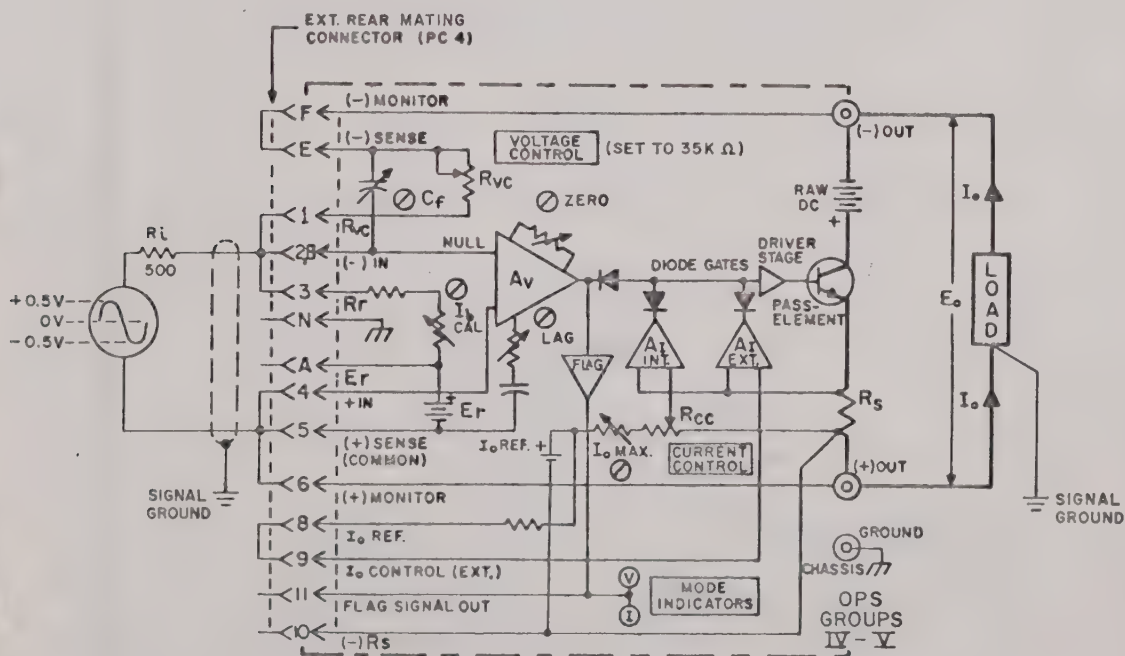


FIG. 3-8 SINE-WAVE PROGRAMMING WITH D-C BIAS.

- 3-33 EXAMPLE II A Model OPS 15 -3M is to be programmed to produce a triangular wave with an amplitude of 15 volts (p-p). The input signal is provided by a Kepco Model FG-100A Function Generator, which can provide a direct, positive 1 milliamper drive. This makes it possible to work without d-c bias and without an input resistor. The input/output waveforms and their phase relationship are shown in FIG. 3-9.

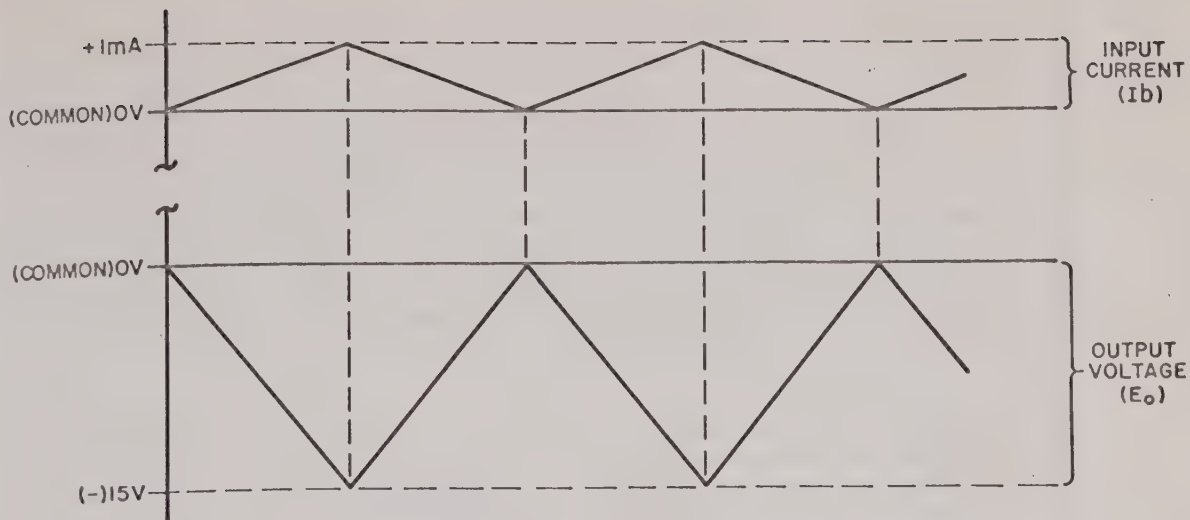


FIG. 3-9 PROGRAMMING WITH A POSITIVE-GOING INPUT SOURCE.

- 3-34 Since I_b in this case is supplied directly from the generator, the internal reference source is disconnected by opening jumper links (2, B) – (3). The front panel VOLTAGE control now serves as the adjustable feedback resistor (R_f – GAIN CONTROL) and is set to the value given by:

$$R_f = \frac{E_o}{I_b} = \frac{15V}{1\text{ mA}} = 15\text{ k ohm (MAXIMUM CLOCKWISE POSITION).}$$

The external components are now connected as shown in FIG. 3-10.

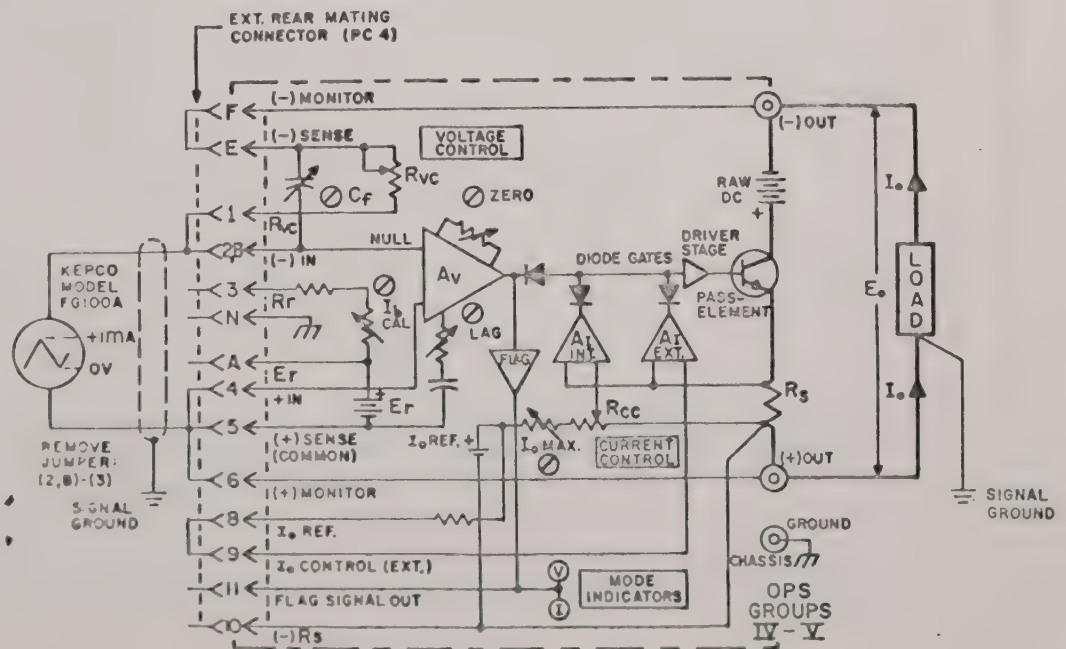


FIG 3-10 CONNECTIONS FOR PROGRAMMING WITH KEPCO FG-100A FUNCTION GENERATOR.

3-35 CALIBRATION. Refer to Section II, FIG. 2-1 for the location of the ZERO calibrating control. Connect an oscilloscope and/or a digital voltmeter across the load, turn OPS and the function generator "on." Set OPS output to "zero" as follows:

- Short the input leads to the "oscilloscope" and set vertical sensitivity to about "5 mV/cm." Set scope base line and note its exact position. Reconnect scope leads across the load.
- Short the feedback terminals (2, B) - (E) on the OPS. If the oscilloscope base line has changed from the previous marked position, correct with the OPS ZERO control, to restore base line to zero position.
- Reset oscilloscope vertical sensitivity control to "2V/cm." Remove short from the OPS feedback terminals. Adjust a convenient sweep speed on the control of the FG-100A and observe trace on the oscilloscope. Correct output amplitude by means of the OPS front panel VOLTAGE control.

3-36 Set OPS front panel CURRENT control for desired load current. Refer to par. 3-17 for the adjustment procedure.

3-37 EXAMPLE III: A Model OPS 36-3M is to be programmed to produce a 30 volt peak-to-peak square-wave output. The available input source is a square-wave generator with a positive "common" and a negative output, able to deliver a 2-volt signal at 1 milliampere. Since in this case, the input signal from the square-wave generator is of the "wrong" polarity, the OPS will be biased to an output of -36 volts and programmed "down" from -36 volts to -6 volts, resulting in the desired output wave. Since *either* the negative *or* the positive output on the OPS may be grounded, this programming arrangement has proven satisfactory in cases where the input signal polarity cannot be changed readily. The expected input and output waveform phase relationships are illustrated in FIG. 3-11. Note: If the negative output side of the OPS is signal grounded, the input generator must be isolated (output to case) for (at least) the OPS output voltage.

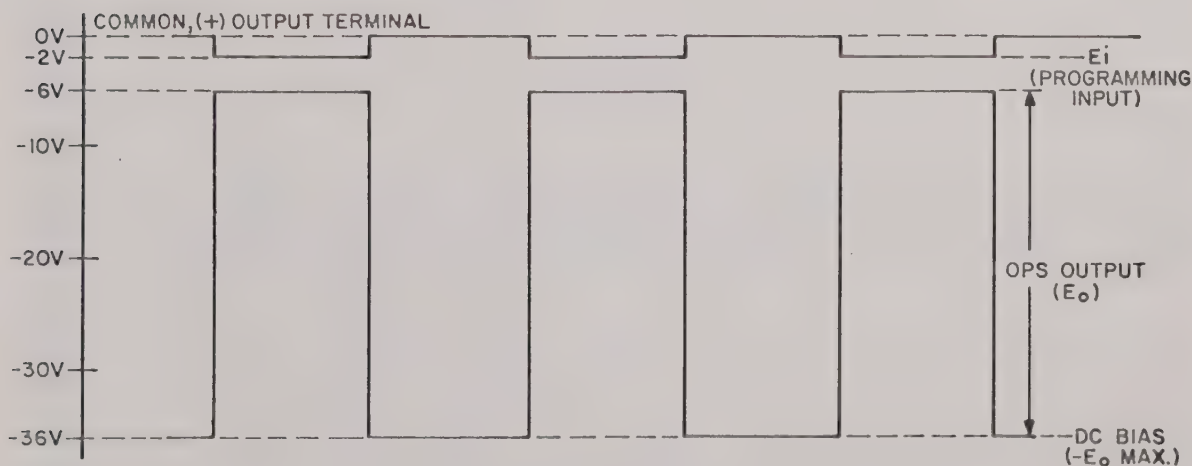


FIG. 3-11 INPUT/OUTPUT WAVEFORMS AND PHASE RELATIONSHIPS.

3-38 The necessary d-c bias (-36 volts) at the OPS output is provided by setting the OPS VOLTAGE control to this value. Now the a-c input signal is applied to the "inverting" input of the OPS voltage-channel amplifier.

The a-c signal conditions are given by the stated parameters:

$$E_o = 30 \text{ volts (p-p)}$$

$$E_i = 2 \text{ volts (p-p)}$$

The required gain $E_o/E_i = 30\text{V}/2\text{V} = 15$, so that the ratio R_f/R_i must also equal 15: Since $R_f = 36 \text{ k ohm}$,⁽¹⁾

$$R_i = 36 \text{ k ohm}/15 = 2.4 \text{ k ohm.}$$

⁽¹⁾NOTE: The value of the front panel VOLTAGE control for the OPS 36-3M is 36 k ohms, if correctly set for (-) 36 volts output.

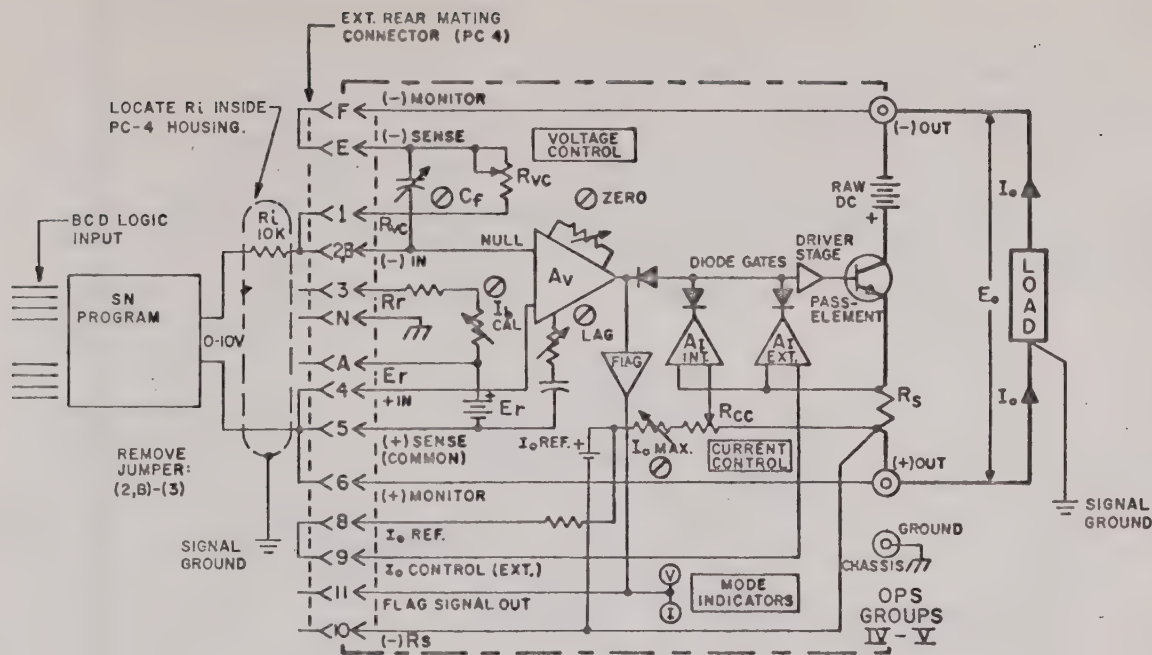


FIG. 3-13 CONNECTIONS FOR PROGRAMMING WITH THE SN PROGRAMMERS.

- 3-45 **CALIBRATION.** Set OPS output to "zero" by shorting the feedback terminals (2, B) – (E) and correct any offset by adjusting the OPS ZERO control. The maximum output from the OPS may be calibrated by programming "full scale" via the SN Programmer and either correcting the setting by means of the built-in FULL SCALE adjustment on the SN Programmer or using the front panel VOLTAGE control of the OPS.
- 3-46 **CURRENT LIMIT ADJUSTMENT.** Set OPS front panel CURRENT control 10% higher than the desired load current. Refer to par. 3-17 for the adjustment procedure.
- 3-47 **DYNAMIC ADJUSTMENTS.** Observe the resulting output waveform by means of a suitable oscilloscope connected across the load. Adjust the provided internal stability controls (LAG and C_f , see Section II, FIG. 2-1) for best waveshape and maximum output stability under all operating conditions. Refer to par. 3-18 for further details on dynamic stability.

PROGRAMMING THE CURRENT CONTROL CHANNEL

- 3-48 **GENERAL.** The function of the current control channel in the OPS has been briefly discussed in par. 3-17 of this section. The control channel has been utilized, in previously described applications, as a current limiter, *controlled locally* by means of the front panel CURRENT control potentiometer. It can, however, be *remotely programmed*, either to function as a current limiter, or to control the OPS as an independent, continuously adjustable current stabilizer. The two basic methods of remotely controlling the current channel of the OPS are described in the following paragraphs.
- 3-49 **OUTPUT CURRENT CONTROL BY POTENTIOMETER.** In this control mode, the front panel CURRENT control potentiometer is set to the *maximum* desired output current value (this control serves as a "back-up" current limit), and a remote potentiometer is connected to the OPS rear connector (PC-4). (Refer to FIG. 3-14. DELETE "E_{CC}" for potentiometer control.)

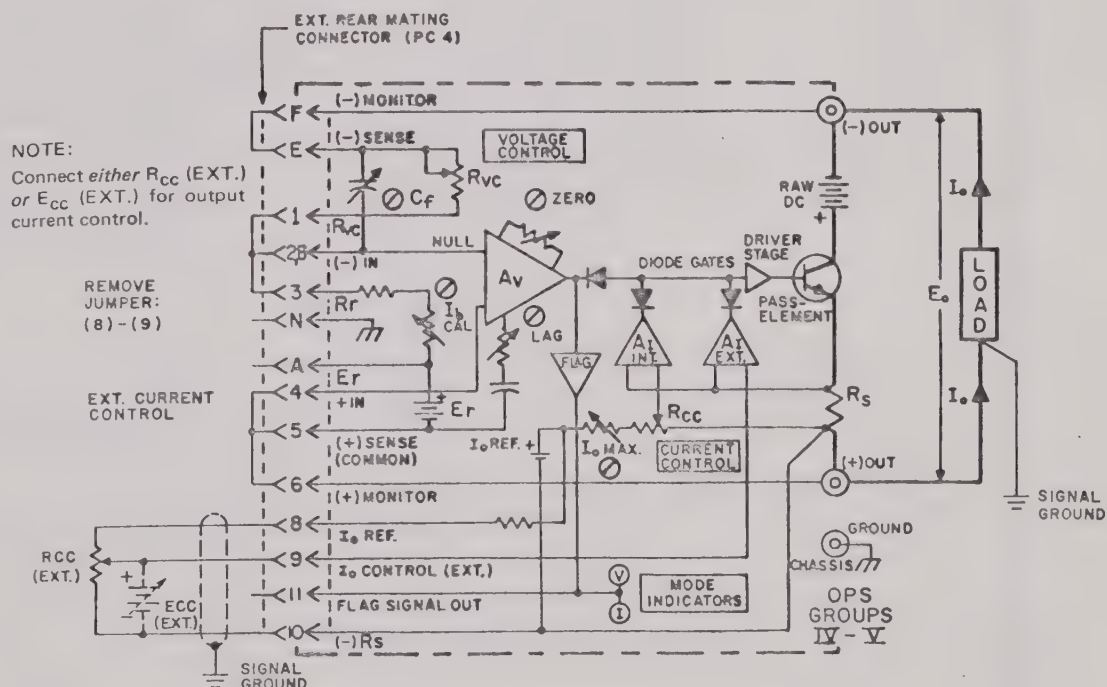


FIG. 3-14 CONNECTIONS FOR REMOTE OUTPUT CURRENT CONTROL BY POTENTIOMETER (R_{CC} EXT.), OR BY EXTERNAL CONTROL VOLTAGE (E_{CC} EXT.).

For OPS models with output current ratings *below* 5 amperes, the value for the external CURRENT CONTROL potentiometer must be 10 k ohms. For OPS models with 5 amperes or greater output current rating, the external CURRENT CONTROL must be 5 k ohms.

OUTPUT CURRENT CONTROL BY AN EXTERNAL CONTROL VOLTAGE. As indicated in FIG. 3-14 (dashed lines), the output current of the OPS can be programmed by means of an external, adjustable control voltage (E_{CC} EXT.) of 0 to 1 volt.⁽¹⁾ (Models with output current ratings *below* 5 amperes, or 0 to 0.5 volts; models with output current ratings of 5 amperes and above.) The method of applying the programming voltage can be as simple as using a potentiometer, connected across a mercury battery, or it can be a digital command with a Kepco SN Programmer as the interface.

As shown in FIG. 3-14, the *voltage* control channel of the OPS remains committed for d-c voltage output and will thus serve as a *voltage limiter*. The voltage channel may be remotely-controlled or front panel adjusted in these applications. For remote control, simultaneously with the current channel, the criteria for component selection as described previously still apply.

⁽¹⁾ Connect external potentiometer (R_{CC} in FIG. 3-14).

THE CONTROL OF OUTPUT CURRENT IN THE mA/ μ A RANGE

3-53 GENERAL. The internal shunt loads and the restrictions imposed by a single internal sensing resistor in the OPS current control channel precludes its use for the control of output currents below about 5 milliamperes. For applications requiring the precision control and stabilization of output currents down to about 1 microampere, an external control mode can be chosen. Three basic circuits are described in the following paragraphs, all utilizing the *voltage channel* of the OPS, with an external feedback circuit to control and stabilize the output current. The current control channel is set to the maximum desired output current and thereby serves as a "back-up" current limit. The selection of one of the three described circuits for a particular application depends on the output current requirements, the desired control mode and the grounding situation at hand. The three circuits are listed below:

- a) EXTERNAL SENSING AND RESISTANCE CONTROL. Suitable for output current control from 10 microamperes to maximum rated value. Positive output grounded (par. 3-56).
- b) EXTERNAL SENSING AND VOLTAGE CONTROL. Suitable for output current control from 1 microampere to 1 milliampere. Positive output grounded (par. 3-63).
- c) EXTERNAL VOLTAGE CONTROL WITHOUT SENSING RESISTOR. Output current from 1 microampere to capability of external control source. Negative output grounded. Suitable for applications where positive grounding cannot be used (par. 3-71).

CAUTION

Since the uncommitted channel is now used for current control, it is no longer available for *voltage* limiting. Voltage limiting is therefore fixed at approximately 150% of the rated output voltage for the given OPS model. If the limiting of the compliance voltage is required, external means (such as zener diodes) may be used across the voltage feedback terminals (2, B) - (E).

3-54 OUTPUT EQUATION. The transfer function for the OPS, with the voltage control channel connected for external sensing and control of the output current, is derived from the equivalent diagram shown below: At $e = 0$ (amplifier input = 0):

$$I_b R_{CC} = (I_o - I_b) R_s \text{ and } I_o = I_b \frac{R_{CC}}{R_s} + I_b \text{ (Eq. 1).}$$

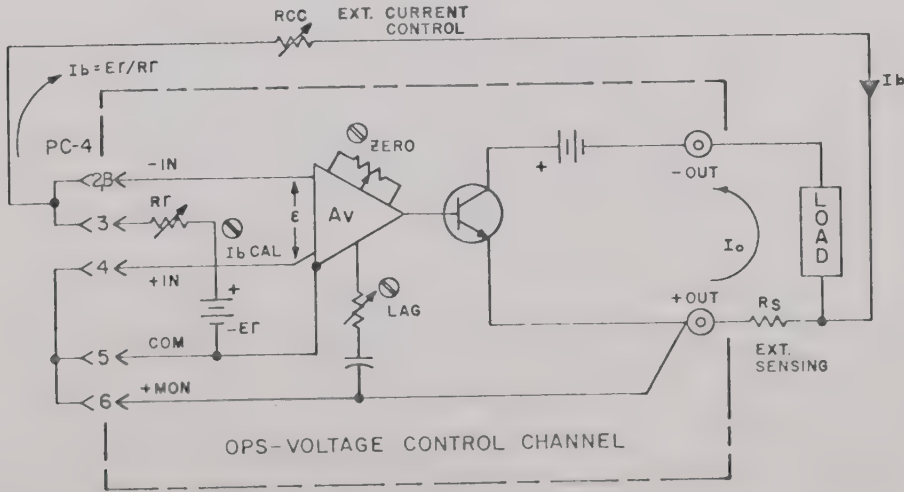


FIG. 3-15 EQUIVALENT DIAGRAM, OPS VOLTAGE CONTROL CHANNEL CONNECTED FOR EXTERNAL SENSING AND CONTROL.

- 3-55 As seen from the output equation (Eq. 1), the *minimum* output current (I_O), with the control resistance zero ($R_{CC} = 0$) is limited to the value of the control current (I_b):

$$I_O \text{ min} = I_b \quad R_{CC} = 0.$$

To allow the output current to go to zero, " I_b " must be "compensated out" by means of a current *equal to*, but flowing in the *opposite* direction. This compensating current can be set up by adjusting the internal ZERO control of the OPS, or for larger offsets, by means of an external compensating circuit. *After* compensation, the output equation (Eq. 1) can be modified to:

$$I_O = I_b \frac{R_{CC}}{R_S}, \quad (\text{Eq. 2}), \text{ which is used for all calculations.}$$

3-56 EXTERNAL CURRENT SENSING AND RESISTANCE CONTROL

- 3-57 COMPONENT SELECTION. The circuit shown in FIG. 3-15 is suitable for output currents from about 10 microamperes to the maximum rated output current for the given OPS model. The circuit components are selected as follows:

- a) CURRENT SENSING RESISTOR (R_S). The value of the current sensing resistor (R_S) is chosen to develop a voltage drop (V_S) of 1 volt at the maximum desired output current ($I_O \text{ max}$):

$$R_S = 1V/I_O \text{ max.}$$

The value of 1 volt for the sensing voltage (V_S) is somewhat arbitrary and the value of R_S may be therefore the closet standard resistance available. A wide departure from the recommended value should, however, be avoided because of the following considerations. While a large value of V_S (and therefore R_S) is desirable for a good signal/noise ratio, the sensing voltage sample is lost at the output and must be subtracted from the available rated compliance voltage. Also, a large sample voltage is not desirable in view of the power dissipation caused in the sensing resistor (R_S). Since all the load current is flowing through R_S and a high-gain amplifier circuit is connected across it, all extraneous changes (such as those caused by self-heating) must be kept as low as possible.

In view of these considerations, it has been found that the recommended value for V_S (1 volt) provides an acceptable signal/noise ratio for current control over a range of 1:50. If a larger range of current must be controlled, a new sensing resistor should be selected. All sensing resistors should be calculated to drop 1 volt at the maximum decade current.

- b) CONTROL CURRENT (I_b). The internal zener voltage source ($E_r = 6.2$ volts nominal) can deliver the required control current (I_b) via the reference resistor (R_r): $I_b = E_r/R_r$. The *optimum* value for I_b is 1 millipere, since the zener source is temperature-compensated for this current. Any value for I_b in the range from 10 microampere to 1.2 millipere can, however, be chosen by adding external reference resistance for the lower values of I_b . Suggested " I_b ," and " R_r " values for various control ranges are given in Table 3-1. The " R_r " values in Table 3-1 are values for the *additional* series resistance to be connected between terminals (3) and (2, B) on PC-4. The control current values (I_b) may be precision adjusted by using the " $I_b \text{ CAL}$ " adjustment, which is in series with the internal reference resistor.

I_O RANGE	I_b	R_r	R_{CC}	R_S
10 mA – 100 mA	1 mA	internal 6.2 k ohms	1000 ohms	10 ohms
1 mA – 10 mA	100 μ A	56 k ohms	10 k ohms	100 ohms
100 μ A – 1 mA	10 μ A	614 k ohms	100 k ohms	1000 ohms

TABLE 3-1 VALUES FOR EXTERNAL SENSING AND CONTROL CIRCUITS.

NOTE: The values in this table are calculated using the output equation (Eq. 1). They are valid for the "zeroed" OPS at a sensing voltage of 1 volt at $I_O \text{ max}$.

- c) **CURRENT CONTROL RESISTANCE (R_{CC}).** The current control resistance may be a fixed resistor, a step-controlled decade box or a rheostat. The resistors should be high-quality components with a minimum temperature coefficient of 20 parts per million. The value of R_{CC} is determined by substituting selected values (for I_O , I_b , and R_S) into the equation (Eq. 2, given in par. 3-55) and solving for R_{CC} . (Refer to Table 3-1 for tabulated values.)

3-58 **EXAMPLE I.** To summarize the material presented in the previous paragraphs (3-53 to 3-57), a circuit for external sensing and resistance control is shown in FIG. 3-16 below. An OPS model is used to deliver stabilized output current from 0–10 milliamperes into a fixed load. From the table of values (Table 3-1) we have:

$$\begin{aligned} I_b &= 100 \text{ microamperes} \\ R_S &= 100 \text{ ohms} \\ R_{CC} &= 10 \text{ k ohms} \\ R_r &= 62 \text{ k ohms (total value. Use 54 k ohms external).} \end{aligned}$$

3-59 Connect all components as shown in FIG. 3-16. The sensing resistor (R_S) should be located as close to the power supply as possible. The leads connecting the control resistance (R_{CC}) must be shielded, with the shield (single-ended) connected to the signal ground. The signal ground point must be carefully selected to avoid ground loops.

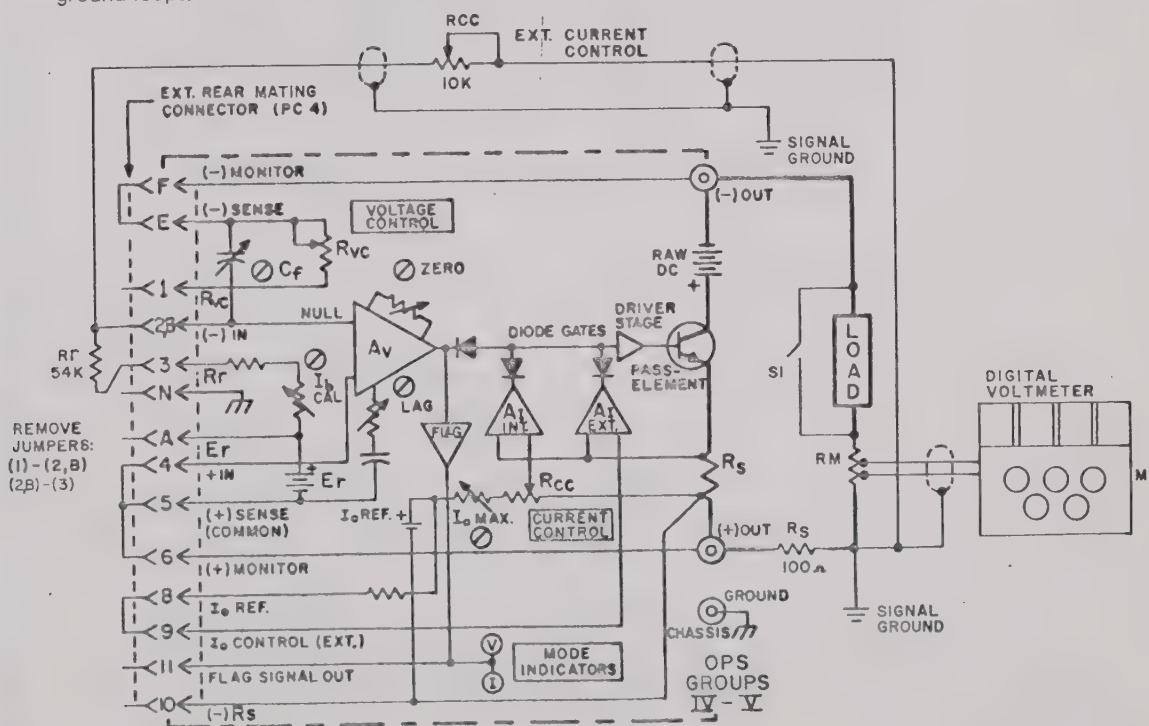


FIG. 3-16 EXTERNAL SENSING AND RESISTANCE CONTROL.

3-60 **CALIBRATING THE OUTPUT.** (Refer to Section II, FIG. 2-1 for location of controls.)

- a) Turn OPS and digital meter "on," and allow the circuit to reach thermal equilibrium. The output current (I_O) is proportional to the voltage across the digital meter and the value of the measuring resistor (R_M):

$$I_O = V_{M1}/R_M. \text{ (SELECT "RM" = "R_S" = 1 volt drop at } I_O \text{ max.)}$$

- b) Set the external CURRENT CONTROL R_{CC} to "zero ohms" (I_O min). If the output current is not "zero" (as read on M1), adjust the ZERO control of the OPS.
- c) Set the external CURRENT CONTROL to its maximum resistance (I_O max). If the output current is not equal to I_O max (as read on M1), adjust the I_b CAL control on the OPS.
- d) Recheck "zero" adjustment by repeating "b."

- 3-61 **OUTPUT MEASUREMENTS.** Output effect measurements may be performed by using the setup shown in FIG. 3-16. For output effects due to a-c source changes, a means of varying the a-c source (variable transformer or "step" device) should be provided. For load effect measurements, the shorting switch (S1) is connected across the load. If the load is now shorted, or the a-c source varied, the deviation of the digital meter (ΔV) divided by the value of the measuring resistor (R_M) represents the output current change (ΔI_O): $\Delta I_O = \Delta V/R_M$. The output effect, in percent of the total output current, can be calculated by:

$$\% \text{ OUTPUT EFFECT} = \frac{\Delta V}{V_{RM}} \times 100, \quad \text{where } V_{RM} \text{ is the total voltage drop across the measuring resistor at the output current of interest.}$$

- 3-62 **OUTPUT RIPPLE AND NOISE.** Output current ripple, as observed with an RMS reading meter or an oscilloscope across R_M , must be converted into current units by dividing the RMS or peak reading by the value of R_M . The ripple amplitude may often be greatly reduced by a capacitor across the sensing resistor (R_S). Since the major ripple component is the a-c source frequency, the capacitor must have a low impedance compared to R_S at this frequency. The capacitor will slow the response to load voltage changes in the OPS. A compromise between the desired response time and the ripple amplitude must therefore be made.

3-63 EXTERNAL CURRENT SENSING AND VOLTAGE CONTROL

- 3-64 **COMPONENT SELECTION.** The use of increasingly smaller control currents and higher resistance values in the control circuit precludes the use of the previously illustrated control methods for output currents below about 10 microamperes. A method without these limitations is described in the following paragraphs. With this method, I_b is eliminated and replaced by an external control voltage.

- 3-65 The transfer function for output control by voltage was derived from FIG. 3-17 and can be expressed by:

$$\left| E_{CC} = I_O R_S \right|_{\epsilon = 0} \quad \text{and: } I_O = E_{CC}/R_S \quad (\text{Eq. 3}), \quad \text{where: } \begin{array}{ll} I_O & = \text{Desired Maximum Output Current} \\ E_{CC} & = \text{External Control Voltage} \\ R_S & = \text{Current Sensing Resistor} \end{array}$$

NOTE: This equation (Eq. 3) is derived from the equivalent diagram (FIG. 3-17), and is valid for the "zeroed" OPS.

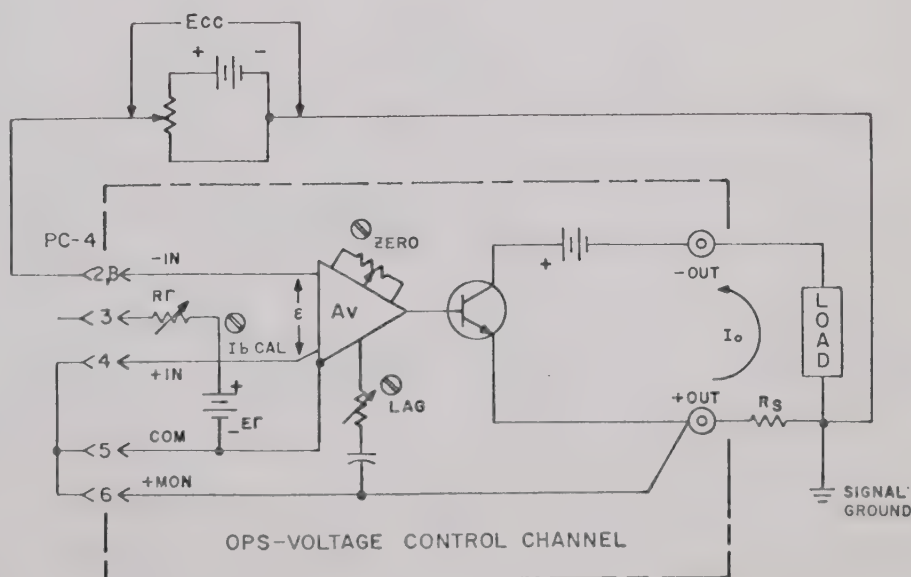


FIG. 3-17 EQUIVALENT DIAGRAM, OPS WITH EXTERNAL SENSING AND VOLTAGE CONTROL.

- 3-66 The circuit shown in FIG. 3-17 is suitable for output current from I_O max of output current down to 1 microampere. The necessary sensing resistors for various current ranges are given in the table for a control voltage (E_{CC}) of 0-1 volt. For other control voltages, they can be calculated using the output equation (Eq. 3)

I_O RANGE:	0–100 μ A	0–1 mA	0–10 mA	0–100 mA	0–1A	0–10A
R_S :	10 k ohms	1 k ohm	100 ohms	10 ohms	1 ohm	0.1 ohm

3-67 The external control voltage (E_{CC}) may simply consist of a potentiometer across a mercury cell (as indicated in FIG. 3-17) or it may be a controlled voltage source of your choice. The voltage source (E_{CC}) must be stable, but its current capacity can be quite small, since it is connected to a high resistance potentiometer and a virtually open circuit (provided the offsets are nulled or zeroed, as previously described in par. 3-60). Note: For Digital control a Kepco SN–2 Programmer may be used.

3-68 EXAMPLE 1. An OPS model is used to deliver stabilized output current from 0 to 100 microamperes. The actual connecting pattern for the circuit with external sensing and voltage control is illustrated in FIG. 3-18. Connect all components as shown in FIG. 3-18, locating the sensing resistor as close as possible to the power supply. The leads connecting the control voltage (E_{CC}) must be shielded, with the shield (single-ended) connected to the common signal ground point. This ground point must be selected carefully, to avoid possible ground-loop effects.

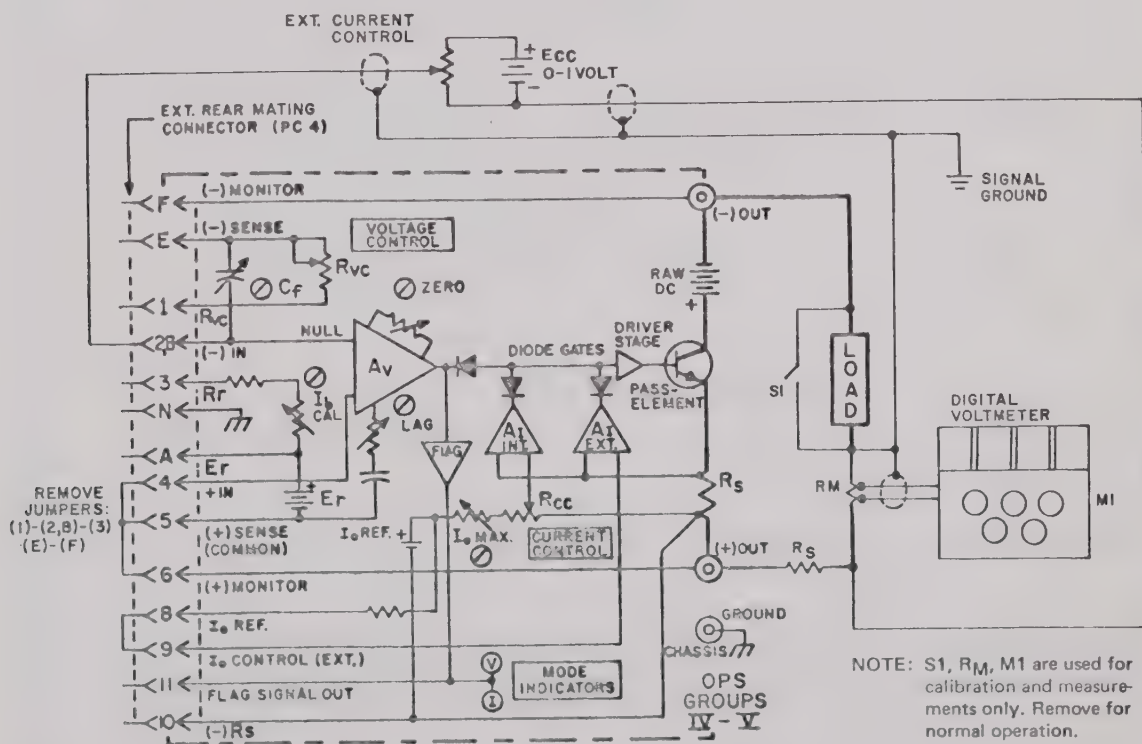


FIG. 3-18 EXTERNAL SENSING AND VOLTAGE CONTROL OF THE OUTPUT CURRENT (I_O max = 100 μ A).

3-69 CALIBRATING THE OUTPUT

- Proceed as described previously in par. 3-60.
- The maximum output current (I_O max) must be calibrated at the control voltage (E_{CC}).

3-70 OUTPUT MEASUREMENTS. Stabilization and ripple measurements may be performed by using the methods described in previous paragraphs. (Refer to pars. 3-61, 3-62.)

3-71 CURRENT CONTROL BY VOLTAGE (WITHOUT SENSING RESISTOR)

3-72 COMPONENT SELECTION. For applications where the negative power supply must be grounded, the output current of the OPS can be controlled by means of an external control source, without the use of a sensing resistor. External component values are selected using the output current equation:

$$I_o = \frac{E_i}{R_i} - I_{io} \quad (\text{Eq. 4}),$$

which is derived from the equivalent circuit shown in FIG. 3-19, and is valid for the "zeroed" OPS.

NOTE: I_{IO} is a small offset current which may be set to zero as shown in par. 3-60. E_i must be able to deliver the output current (I_O) and the compliance voltage required across the load.

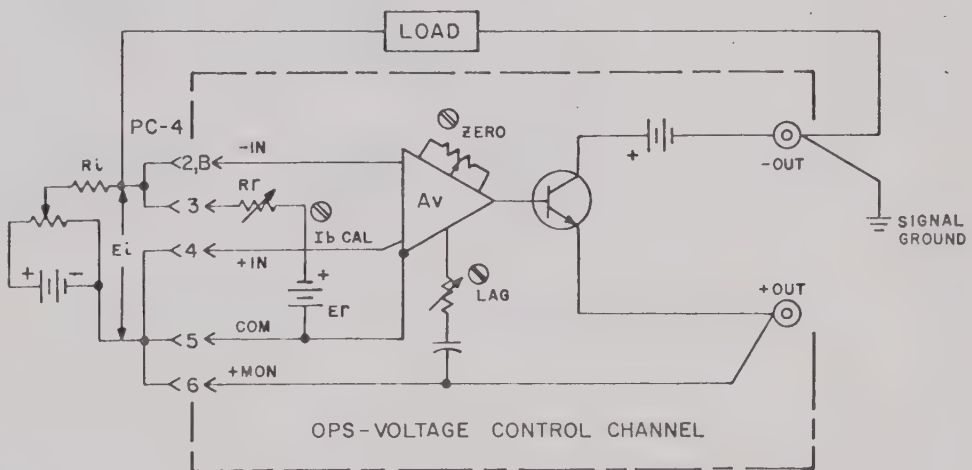


FIG. 3-19 EQUIVALENT DIAGRAM, OPS CURRENT CONTROL WITHOUT SENSING RESISTOR.

373 The circuit shown in FIG. 3-19 is suitable only for output currents which can be supplied by the external control source (the OPS acts as a "controller" only). The circuit is very useful, however, for applications requiring very small output currents, where the negative output side of the OPS (or the load) must be grounded.

374 The external control source is loaded with a potentiometer to draw approximately 1 milliampere, while the control voltage (E_i) is taken between the potentiometer's center tap and "common." The control voltage (E_i) can now be varied between zero and E_i (MAX). A series resistor (R_i) connected as shown (refer to FIG. 3-19) completes the control circuit. The value of R_i depends on E_i (MAX) and is found by using equation (4). E_i must in turn, be able to deliver the necessary compliance voltage across the load. The values given in FIG. 3-20 are for $I_O = 100 \mu A$ ($E_O = 6V$). Stabilized output current in the range from 0 to 100 microamperes can now be adjusted as the current control potentiometer is varied between its limits. The actual interconnections are illustrated in FIG. 3-20.

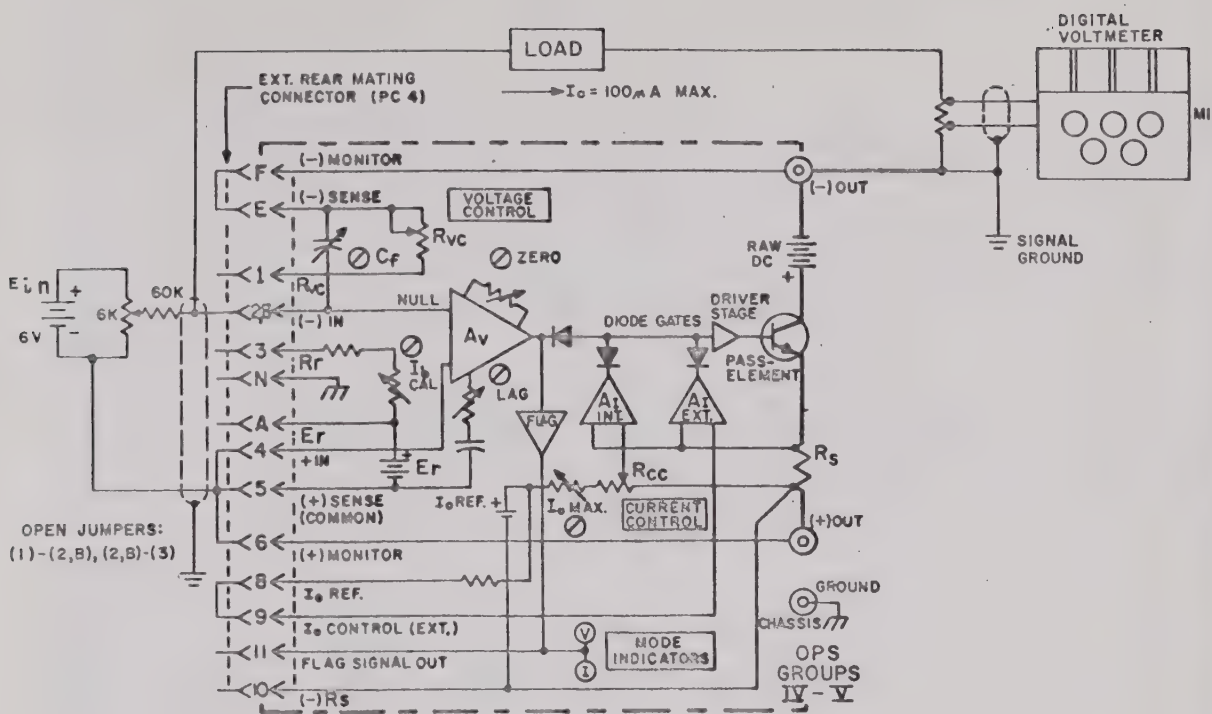


FIG. 3-20 CURRENT CONTROL BY VOLTAGE (WITHOUT " R_s ").

3-75 CALIBRATING THE OUTPUT

- Proceed as described previously in par. 3-60.
- The maximum output current ($I_o \text{ max}$) can be adjusted by making " R_i " partially adjustable.

3-76 OUTPUT MEASUREMENTS. Stabilization and ripple measurements may be performed by using the methods described in previous paragraphs. (Refer to pars. 3-61, 3-62.)

NOTE: The operating section of an instruction manual can only serve as a guide, and cannot possibly cover all aspects of operational power supply programming. The concept of "Resistance Programming," for example, can be extended to include control with other than the standard 1000 ohms/volt ratio, or the control by inverse resistance ("Conductance Programming"). All OPS Power Supplies can be operated in a series or parallel mode with control from a common "Master" unit. Many of the described operating modes can be combined, as for example, in a simultaneous voltage channel/current channel control mode. For further details on these and other programming methods, or for information concerning *your* specific application, please contact the Kepco Applications Engineering Department, Flushing, New York.

SECTION IV — THEORY OF OPERATION

4-1 GENERAL

- 4-2 A *Standard Power Supply* is not well suited for tasks requiring a fast output response. It is generally optimized as a *Voltage Source* and its bandwidth is deliberately restricted, mainly by means of a large output capacitor. The standard power supply is designed to approach the characteristics of an ideal voltage source: low output ripple, low source resistance and a large storage capability.
- 4-3 By contrast, an *Operational Power Supply* exhibits the characteristics deliberately suppressed in a standard power supply: wide bandwidth and fast output response. The wide-band characteristic is achieved by removing the large capacitor at the output and shaping the open-loop response by means of lag networks. The trade-offs which must be accepted are: higher output ripple and output impedance and restrictions on reactive loading.
- 4-4 An *Operational Power Supply* can, however, perform tasks which would be impossible for a standard supply: as a *D-C Power Source*, it can be programmed to provide high speed voltage or current level changes. As a *Unipolar Power Amplifier*, it can amplify unipolar or bipolar waveforms to power levels limited only by its own output ratings. As an *Operational Amplifier* it can serve as a summer, scaler or integrator, and can perform any other operational task. In addition, the Operational Power Supply, with its wide bandwidth and its fast response to load voltage changes, is ideally suited to function as a *Stabilized Current Source*.

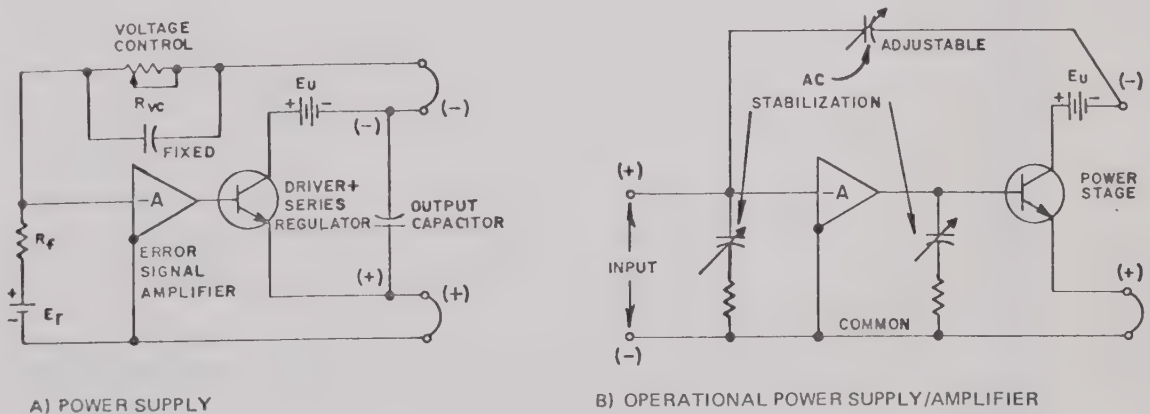


FIG. 4-1 COMPARISON STANDARD POWER SUPPLY WITH AN OPERATIONAL POWER SUPPLY.

4-5 OPERATIONAL POWER SUPPLY SPECIFICATIONS

- 4-6 GENERAL. The performance of Operational Power Supplies is described in terms of the following parameters:
- 1) D-C OFFSET VARIATIONS.
 - 2) OPEN-LOOP GAIN (Specified at d-c).
 - 3) MAXIMUM SLEWING RATE.
 - 4) MAXIMUM SINE WAVE FREQUENCY (FULL POWER).
 - 5) PROGRAMMING TIME CONSTANT.
- 4-7 Since there are no established standards to describe the behavior of Operational Power Supplies, the terms used by Kepco, Inc., are defined in the following paragraphs. The discussion includes the test circuitry used to establish the specifications, as well as notes on their application.
- 4-8 D-C OFFSET VARIATIONS. Any power supply, "standard" or "operational," consists of a comparison amplifier, a reference source and a power amplifier or series regulator section. (Refer to FIG. 4-1.) The effects of various external influences, such as time, temperature, load or a-c source variations upon the d-c output of any power supply are due to small variations at the input of the comparison amplifier. These small errors or "offset variations" are transferred to the output, amplified by a factor which depends on the gain (ratio of reference voltage to output voltage) and the value of the feedback resistor (voltage control resistor) at any given output level. Since a "standard" power supply has only a limited range of gain and feedback resistance,

the total "worst case" error can be specified *directly* as an *output effect* in response to the various *Influence Quantities*. In an operational power supply, however, the gain and the feedback resistor are selected by the user and may, therefore, vary over a much wider range. For this reason, the *offset variations* are specified for the power supply amplifier input. Once the user has selected the feedback components and the required gain for the application at hand, the output effects can be calculated by means of the *error equation*.

4-9 As seen from FIG. 4-1, an operational power supply can be represented as an amplifier, driving a power stage in series with the raw d-c source. It can, therefore, be analyzed using operational amplifier terminology. The circuit shown in FIG. 4-1 is further simplified by including the power stage and the raw d-c source into the amplifier triangle. Adding an input source (E_i) with a series resistor (R_i) and a feedback resistor (R_f), a model of an "ideal" operational amplifier (inverting configuration) results, for which the following assumptions are made:

- 1) The offset current (I_{i0}) at the input terminal (Null Junction) *approaches* zero.
- 2) The open-loop gain (A) *approaches* infinity ($A \rightarrow \infty$).
- 3) The input voltage (E_{i0}) *approaches* zero, when the feedback loop is closed.

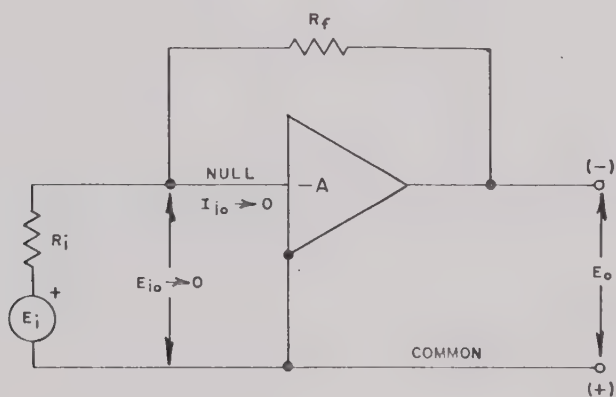


FIG. 4-2 MODEL OF IDEAL OPERATIONAL AMPLIFIER WITH FEEDBACK (INVERTING CONFIGURATION).

4-10 Refer to FIG. 4-2. If the input error voltage and current (E_{i0} , I_{i0}) are assumed to be zero, and the gain is infinite, we can write:

$$\frac{E_i}{R_i} = \frac{E_o}{R_f}, \quad (\text{Eq. 1})$$

or in the more familiar form,

$$E_o = -E_i \left(\frac{R_f}{R_i} \right) \quad (\text{Eq. 2}),$$

where, the ratio R_f/R_i represents the closed-loop gain. Equation (2) thus becomes the transfer function for the operational amplifier in an inverting configuration. Although the expression (Eq. 2) was derived for the "ideal" case, it may be readily applied to the practical operational power supply circuit. The transfer function (Eq. 2) is, for example, extensively used to calculate the values for the input and feedback resistors, since the associated errors are negligible compared to standard component tolerances. These errors neglected in the "ideal" model must, however, be considered in evaluating the d-c performance at the output of an active operational power supply.

4-11 **AMPLIFIER OFFSETS.** In developing the ideal amplifier model, we tacitly assumed the null junction voltage and current to be zero causing the "ideal" equation (2) to be valid. In reality, however, nonidealities do exist at the null junction or input terminal of the amplifier. These errors are of the form of an offset voltage (E_{i0}) and an offset current (I_{i0}). The modified version of the amplifier model can be shown with these error sources as in FIG. 4-3.

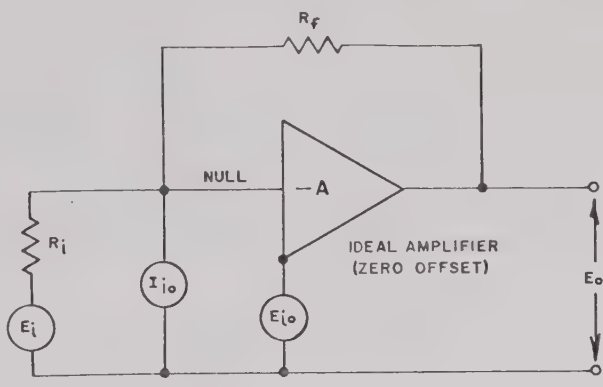


FIG. 4-3 AMPLIFIER WITH INPUT OFFSET SOURCES.

4-12 Although the INITIAL values of both offsets (E_{i0} , I_{i0}) may be cancelled by compensating sources of opposite polarity,⁽¹⁾ the VARIATIONS of the offsets (ΔE_{i0} , ΔI_{i0}) and the variation of the internal reference voltage (ΔE_i) with a-c input source, d-c load, temperature, and time changes *do* exist at the amplifier input and are specified as shown in the table (Table 4-1).

INFLUENCE QUANTITY	OFFSET VARIATIONS		REFERENCE (6.2V $\pm$ 5% NOMINAL) VARIATIONS
	ΔE_{i0}	ΔI_{i0}	
A-C INPUT SOURCE: (105 to 125V or 210 to 250V)	< 5 μ V	<1 nA	0.0005%
LOAD: No load to full load	<100 μ V	<5 nA	NOT APPLICABLE
TIME: 8 hrs. (Drift)	< 20 μ V	<1 nA	0.005%
TEMPERATURE: Per $^{\circ}$ C	< 20 μ V	<2 nA	0.002%

TABLE 4-1 TYPICAL OFFSET SPECIFICATIONS FOR OPERATIONAL POWER SUPPLIES.

4-13 For a "worst case" analysis of the effects these tabulated errors have at the output of the operational power supply, their algebraic sum can be expressed by the "Error Equation" (Eq. 3):

ΔE_o
WORST CASE TOTAL OUTPUT EFFECT

$=$

$\pm \Delta E_i (R_f/R_i)$
OUTPUT EFFECT DUE TO VARIATIONS IN REFERENCE VOLTAGE

$\pm$

$\Delta E_{i0} (1 + R_f/R_i)$
OUTPUT EFFECT DUE TO OFFSET VOLTAGE VARIATIONS

$\pm$

$\Delta I_{i0} R_f$
OUTPUT EFFECT DUE TO OFFSET CURRENT VARIATIONS

(Eq. 3)

NOTE Changes in R_f and R_i as a function of time and temperature are neglected in the above equation. In practical applications, R_f and R_i should have low, matched temperature coefficients, for optimum d-c stability.

Power Supplies have a built-in control, to zero E_{i0} (R12 - "zero"). No control is provided for zeroing I_{i0} , since its value is not significant for most applications. I_{i0} may be zeroed, however, (for very critical d-c applications with large feedback resistors) using an external nulling circuit. Please contact the KEPCO Applications Department for detailed information.

4-14 An inspection of the individual terms of the error equation (Eq. 3) re-emphasizes the previously discussed reasons for specifying all error voltages separately at the *input* to the power supply amplifier: The magnitude of the *output effects* caused by the individual errors (ΔE_i , ΔE_{iO} , ΔI_{iO}) depend on the *ratio* of the feedback and input resistor (R_f/R_i = closed-loop gain) and on the *value* of the feedback resistor (R_f). Since the gain and the input/feedback components are selected by the user, the total output effect (ΔE_O) must be calculated for each application by means of the error equation. The separation of the terms in the error equation allows the analysis of the contribution of each error to the total output effect and permits component selection so as to minimize the total effect.

4-15 A practical example should illustrate the use of the derived equations and the offset specifications: A Model OPS 75-0.75M is used as a d-c voltage source in an application requiring 62 volts into a constant load. The available a-c source voltage is stable, but the temperature in the operating environment changes over a range of 10°C. The effect of this temperature change on the output voltage of the OPS is to be predicted.

In this application, the internal reference voltage (E_r = 6.2V nominal) may be used in series with an external reference resistor (R_r) to produce the required 1 milliampere control current (I_b). If these predetermined values are substituted into the "ideal" transfer function, the value of the feedback resistor for 62 volts output is given by:

$$R_f = E_O (R_i/E_r) = \frac{62V \times 6.2 k}{6.2V} = 62 k \text{ ohms,}$$

and the closed-loop gain (R_f/R_i) equals $62 k/6.2 k = 10$.

Inserting the selected values for R_i and R_f and the offset specifications (from Table 4-1) into the error equation (Eq. 3), the output effect due to the anticipated temperature change can be predicted:

$$\begin{aligned} \Delta E_O &= 124 \mu V (10) + 20 \mu V (1 + 10) + 2 \text{ nA } (6.2 \times 10^4 \Omega) \\ &= 1.24 \text{ mV} + 0.22 \text{ mV} + 0.124 \text{ mV} = 1.58 \text{ mV per } ^\circ\text{C.} \end{aligned}$$

OUTPUT EFFECT
DUE TO
REFERENCE
VARIATION

OUTPUT EFFECT
DUE TO
OFFSET VOLTAGE
VARIATION

OUTPUT EFFECT
DUE TO
OFFSET CURRENT
VARIATION

or 15.8 mV output voltage change over the 10°C temperature range. It should be noted, that the calculated total output effect (ΔE_O) represents a "worst case" prediction, assuming all error terms are positive. In practice, this is not the case. A TYPICAL value for the above example would be considerably smaller, as actual measurements on large numbers of operational power supplies have shown.

4-16 OPEN-LOOP GAIN. In the "ideal" transfer function for the operational power supply (Eq. 2), the open-loop gain (A) was assumed to be infinite. In reality, however, it is finite and in the order of 10^5 to 10^7 (volts per volts). Although operational power supplies are seldom used in an open-loop configuration, the open-loop gain (A) is of interest since it provides a measure of the possible programming linearity. Finite open-loop gain introduces a "gain error" into the "ideal" transfer function (Eq. 2), which limits the absolute closed-loop accuracy and gain linearity. While the absolute closed-loop *accuracy* can be "calibrated away" by adjusting the feedback resistor, the *gain linearity* cannot be corrected. The specified open-loop gain (A), specified at d-c, is a measure of that linearity. To illustrate the significance of the open-loop gain, consider the modified transfer function for the operational power supply in the inverting configuration:

$$\frac{E_O}{E_i} = \frac{(R_f/R_i)}{1 + \frac{1}{A\beta}}, \quad (\text{Eq. 4}),$$

where the "ideal" closed-loop gain ($E_O/E_i = R_f/R_i$) is modified by the error term $1/A\beta$, where A is the open-loop gain, and β represents the feedback ratio (R_i/R_f) (Approximately).

4-17 Assuming that the resistors (R_f , R_i) do not contribute to the gain error, consider an application where:

Specified Open-Loop Gain (A) d-c = 10^6 volts/volt.

Ideal Closed-Loop Gain (R_f/R_i) = 10^2 .

The gain (linearity) error, due to finite open-loop gain, in this case equals: $\frac{1}{A \frac{R_i}{R_f}} = 1/10^4$, or 0.01%.

4-18 DYNAMIC SPECIFICATIONS.

4-19 GENERAL. The output behavior of the operational power supply can be described by two major parameters: The PROGRAMMING TIME CONSTANT and the MAXIMUM SLEWING RATE. The first describes the output response in the linear region while the other represents the output response to overdriven or forced input signals in the nonlinear region.

4-20 PROGRAMMING TIME CONSTANT. The programming time constant (τ) is the time required for an output voltage step to change from 0 to 63% of its final value.

The programming time constant expresses the programming speed in the linear region of the operational power supply. It is approximately equal to the product of the selected feedback capacitance (C_f) and feedback resistance (R_f). It is measured as the first time constant on the exponential output response.

4-21 The "programming time constant" (τ) can readily be translated into the frequency domain, thus yielding the upper "3 dB frequency;" i.e., the highest sine wave frequency the operational power supply output can reproduce in its linear region. Since the programming time constant (τ) represents the rise time of the output voltage (0–63% E_o), it is inversely proportional to the upper 3 dB frequency (f_2):

$$t_r (0-63\%) = \tau = \frac{1}{\omega_2} = \frac{1}{2\pi f_2} = \frac{0.16}{f_2}. \text{ If, for example, } \tau = 100 \mu\text{sec.}, f_2 = 1.6 \text{ kHz.}$$

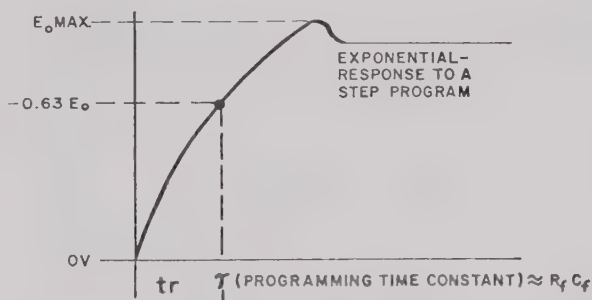


FIG. 4-4 DEFINITION OF THE PROGRAMMING TIME CONSTANT.

4-22 MAXIMUM SLEWING RATE. The maximum slewing rate is the fastest time rate of change of which the operational power supply is capable. The slewing rate is specified with the output fully loaded and measured as the output response to an input step function. As the exponential response to a step-input (such as a square wave, for example) is displayed on an oscilloscope, a slight increase in input amplitude will make rate limiting evident on the rising portion of the output waveform. (See FIG. 4-5).

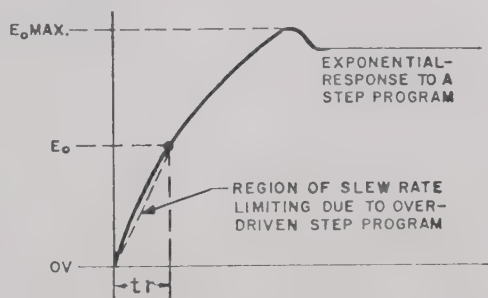


FIG. 4-5 DEFINITION OF MAXIMUM SLEWING RATE.

4-23 If a further increase of the driving signal amplitude does not produce a further change in the (E_o/t_r) slope of the displayed output response, the operational power supply is responding with the maximum slewing rate. The ratio E_o/t_r is measured over any convenient scale and the result is expressed in volts per microsecond.

4-24 If the input driving signal is a sinusoidal waveform instead of a step-function, the output waveform from the operational power supply is also a sinusoid. The maximum sine wave frequency which can produce the full output voltage (regardless of gain) is limited by the maximum slewing rate. The MAXIMUM SLEWING RATE and the FULL POWER SINE WAVE FREQUENCY ($f_{\max}$) are related by the equation:

$$\text{SLEWING RATE} = \pi f_{\max} E_{p-p}$$

where E_{p-p} represents the peak-to-peak output voltage of the operational power supply. The FULL POWER SINE WAVE FREQUENCY is specified for the frequency, where 5% total harmonic distortion

4-25 SIMPLIFIED DIAGRAM DISCUSSION (Refer to FIG. 4-6)

4-26 The POWER TRANSFORMER converts the a-c source voltage to the levels required to produce the d-c operating potentials for the MAIN D-C SOURCE and the AUXILIARY D-C VOLTAGES. The MAIN D-C SOURCE is connected in series with the POWER OUTPUT STAGE, the CURRENT SENSING RESISTOR (R_s) and the external load, which will be connected to the ($\pm$) OUTPUT terminals. The output level of the OPS is controlled by varying the series impedance of the POWER OUTPUT STAGE. The necessary drive to affect this control is provided by the DRIVER STAGE, which in turn receives its drive either from the VOLTAGE MODE or one of the CURRENT MODE AMPLIFIERS.

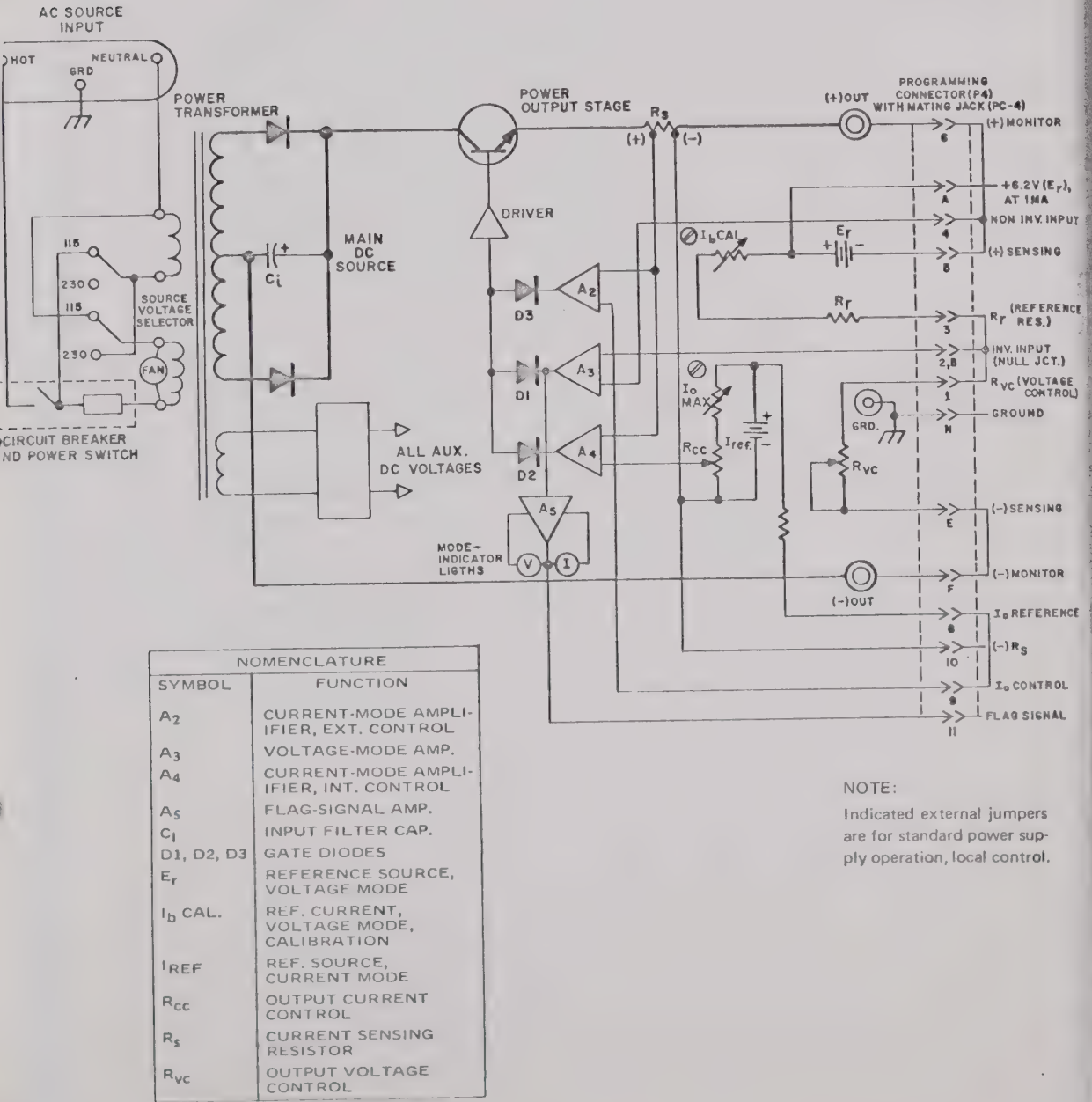


FIG. 4-6 SIMPLIFIED DIAGRAM, OPS GROUP IV, V.

- 4.27 If the OPS is used with the internally provided d-c reference source and with all internal feedback and reference resistors connected as shown in FIG. 4-1, it functions as a d-c source delivering stabilized output voltage or current to the load. The operating mode ("voltage" or "current") is determined by the load resistance and by the setting of the VOLTAGE CONTROL (R_{VC}) and the OUTPUT CURRENT CONTROL (R_{CC}). If, in FIG. 4-7, " E_o " (voltage) and " I_o " (current) represent the respective settings of the output controls, the "crossover" resistance (R_{LX}) is given by Ohm's Law:

$$R_{LX} = E_o / I_o.$$

- 4.28 Any load resistance, *smaller* than R_{LX} (as, for example, R_{LI} in FIG. 4-7) will transfer the OPS into the "Current Mode." With any load resistance *larger* than R_{LX} (as, for example, R_{LV} in FIG. 4-7), the OPS will operate in the "Voltage Mode."
- 4.29 Connected as a d-c source (as shown in FIG. 4-1), the OPS output voltage and current are constantly monitored and compared to the internal temperature-compensated REFERENCE SOURCES (E_r , I_{ref}). The VOLTAGE-MODE and CURRENT-MODE AMPLIFIERS (A3, A4) operate as "Error-Signal Amplifiers," and at balance, the settings of the output controls and the value of the load resistance establish a given operating point on the output characteristic, as described previously. A change in either output control setting, or an external influence on the set output quantities (change in load, variations in a-c source voltage) are interpreted by the OPS sensing circuits as "Error Signals." Depending on the prevailing operating mode of the OPS, the "error signal" is amplified by either the VOLTAGE-MODE or the CURRENT-MODE AMPLIFIER. The amplified error signal is presented to the OR-GATE (D1, D2), which only passes the most negative signal, so that only *one* of the amplifiers can be in control at any one time. Once the amplified error signal is passed by the OR-GATE, it becomes a "control signal" which, amplified by the DRIVER STAGE, is applied to the base of the transistors in the POWER OUTPUT STAGE. The power transistors in this stage change their series impedance in response to the control signal from the DRIVER STAGE. The control signal was derived from the "error signal" and is, therefore, proportional to the original output variation of the OPS. The resulting series impedance change in the POWER OUTPUT STAGE is, therefore, exactly inversely proportional to the original output variation, so that the OPS output is returned to the original value and thereby stabilized.
- 4.30 If the OPS is operated as a (unipolar) power amplifier, the INVERTING INPUT of the VOLTAGE-MODE AMPLIFIER is disconnected from the internal d-c reference source. The OPS output responds now to control signals applied to the INVERTING INPUT (Null Junction) with reference to the COMMON (+ SENSE) terminal. The gain in these applications is directly proportional to the ratio of the input resistor (R_i , connected to the INVERTING INPUT in series with the control signal) and the feedback resistor [either the internal VOLTAGE CONTROL (R_{VC}) or an EXTERNAL RESISTOR (R_f)], connected from (2, B) to (E) on PC-4. The output of the OPS is "unipolar," varying in a single direction. The current control channel in this application is used as a "current limiter" by setting the CURRENT CONTROL to the maximum desired output current.
- 4.31 The current control channel has an additional amplifier (A2), which may be remotely programmed, either by an external potentiometer, or by an external control voltage. Directions for remote control are given in Section III of this manual.

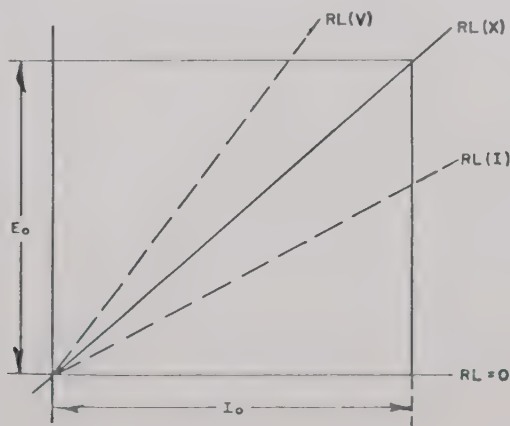


FIG. 4-7 "CROSSOVER" CHARACTERISTICS, OPS GROUPS IV, V.

4-32 CIRCUIT DESCRIPTION

4-33 For the purpose of description, the circuitry of the OPS Power Supply may be divided into several sections which are individually described below. The main schematic (FIG. 6-1) should be used to illustrate the text of this section.

- a) **A-C INPUT CIRCUIT.** A-C line power is introduced through the (detachable) 3-wire line cord with safety plug. The use of a grounded a-c power outlet will automatically ground the power supply, since the third wire of the line cord is directly connected to the metal chassis and case. Once the a-c power switch/circuit breaker (CB101) is closed, the primary of the main transformer (T201) and the fan (B201) *will be energized*. The two primary windings of the main transformer are either connected in parallel (for 115V a-c nominal line voltage) or in series (for 230V a-c nominal line voltage) by means of the a-c source selector (S201). The circuit breaker/power switch (CB101) protects the power supply from overloads and shuts off automatically if activated. The sensing coil of CB101 is connected in such a way that equal protection is provided, whether the a-c source selector (S201) is set to 115V or 230V.
- b) **MAIN D-C SUPPLY.** The main d-c power is derived from a center-tapped secondary winding on T201. A full-wave rectifier circuit with silicon diodes CR301, CR302 (located on the heat sink assembly) works into a capacitor input filter (C201), paralleled by a bleeder resistor (R201). The main d-c supply delivers the output current through the series regulator or pass element (POWER OUTPUT STAGE).
- c) **POWER OUTPUT STAGE.** This stage consists of a number of Darlington driven power transistors (Q301–Q3 . . . , the exact number depending on the OPS model number) which are mounted onto a common, forced-air cooled heat sink (Assembly A3). The power output stage can, (for analytical purposes) be considered as a single transistor, which is connected in series with the raw d-c supply, the sensing resistor and ($\pm$) output terminals. The output of the OPS is controlled by changing the series impedance of the power transistors in response to drive signals from the driver stage (Q1). The driver stage, in turn, fed by the constant current stage (Q2) and controlled by either the voltage-mode amplifier (IC–1) or one of the current-mode amplifiers (IC–3,4).
- d) **VOLTAGE CHANNEL.** If the OPS is used as a stabilized d-c voltage source, the voltage-mode amplifier (IC–5) serves as a comparator. The output voltage is sensed at the error-sensing terminals (P4–5,E) and compared with the reference voltage, produced across the zener diode (CR14), at the inverting input (P4–2, B) of the voltage-mode amplifier (IC–5). This device is a high-gain, integrated circuit amplifier. Any deviation in the output voltage of the OPS, caused by a-c source changes, load variations, or control setting, will produce an error signal at the inverting input (Null Junction) of IC–5. The amplifier then produces an control signal which passes the gate diode (CR15) and provides the base signal for the driver stage (Q1). The drive from Q1 is phased and proportioned to influence the POWER OUTPUT STAGE in such a way as to compensate exactly for the original output error.
- e) Both inputs of the voltage-mode amplifier (IC–5) are brought out at the rear programming connector P4–2, B = INVERTING INPUT, P4–4 = NONINVERTING INPUT) and may be used for programming with voltage or current signals of either polarity. The amplifier is stabilized by a lag network (C13–R32) which can be adjusted for optimum dynamic performance. The amplifier offset is compensated by the ZERO control (R27). An adjustable feedback capacitor (C14) is connected from the INVERTING INPUT (P4–2, B) to the (–) sensing terminal (P4–E).

- f) **CURRENT CONTROL CIRCUIT (LOCAL).** The differential input of the current-mode amplifier (IC-3) is connected to the current-sensing resistor (R305) to the output current control (R102) fed by a reference current source (Q3, Q4). The output current control can be adjusted (front panel control) over a range from <2% to 105% of this maximum rated output current of the power supply. Once the current control is set, the current generated by the constant current source (Q3, Q4) establishes a voltage drop across a portion of the current control resistor (R102), which is continuously compared to the voltage drop across the sensing resistor (R305). If the voltage drop across R305 (proportional to the flow of the output current) approaches the reference voltage selected by R102, an error signal is developed at the input of the current-mode amplifier (IC-3). The amplified error signal passes the gate diode (CR12) taking control away from the voltage-mode amplifier (IC-5) and transferring the power supply into the "current mode" of operation. Simultaneously, the flag-signal amplifier (IC-2) reverses the flag signal polarity at the programming connector (P4-11) and energizes the "I" mode indicator (DS102).
- g) **CURRENT CONTROL CIRCUIT (REMOTE).** A separate amplifier (IC-4) and a reference current (via R28) is made available at the rear programming connector (P4-8) for remote operation of the current control function of the OPS Power Supply. For remote control, an external current control potentiometer must be connected to the rear programming connector (P4-8, 9, 10). The constant current source (Q3, Q4) establishes a reference voltage across the external current control, a portion of which is compared with the voltage drop across the current-sensing resistor (R305). As this sensing voltage increases (due to increasing output current flow) and approaches the reference voltage set by the external CURRENT control, the current-mode amplifier for external control (IC-4) develops an error signal which passes the gate diode (CR13) and transfers the power supply into the current mode. A flag signal (polarity reversal at P4-11) is produced by IC-2, which also energizes the front panel mode indicator "I" (DS102).

NOTE: Since the internal, local (front panel) control for setting the output current is not removed for remote operation, this control may be used as a "back-up" adjustment. It should be set to a *higher* value than the remote control, since the control with the *lower* setting acts as an active CURRENT control.

SECTION V — MAINTENANCE

5-1 GENERAL

- 5-2 This section covers maintenance procedures, installation of optional components, calibration and test measurements of the Kepco OPS GROUP IV and V Power Supplies. Conservative rating of components and the noncongested layout should keep maintenance problems to a minimum. If trouble does develop, however, the easily removed wrap-around cover and the plug-in feature of the circuit boards provide exceptional accessibility to all components of the supply.

5-3 DISASSEMBLY (Refer to FIG. 5-1)

- a) **COVER REMOVAL.** The wrap-around cover may be taken off by loosening and removing its (10) holding screws, (4) on each side and (2) on the front panel.
- b) **CIRCUIT BOARD REMOVAL.** The printed circuit board is mounted with (4) screws, (2) of which are removed from the rear, (2) from the side. After removal of the (2) printed circuit board connectors, the board may be lifted from its slide-guide.
- c) **HEAT SINK REMOVAL.** The heat sink assembly is mounted with (3) screws to the chassis bottom. After the screws are taken out, the wires may be removed by means of the "Quick-disconnect" terminals and the printed circuit board connector.
- d) **REASSEMBLY.** Reassembly of all components takes place in reverse order of the above described procedures.

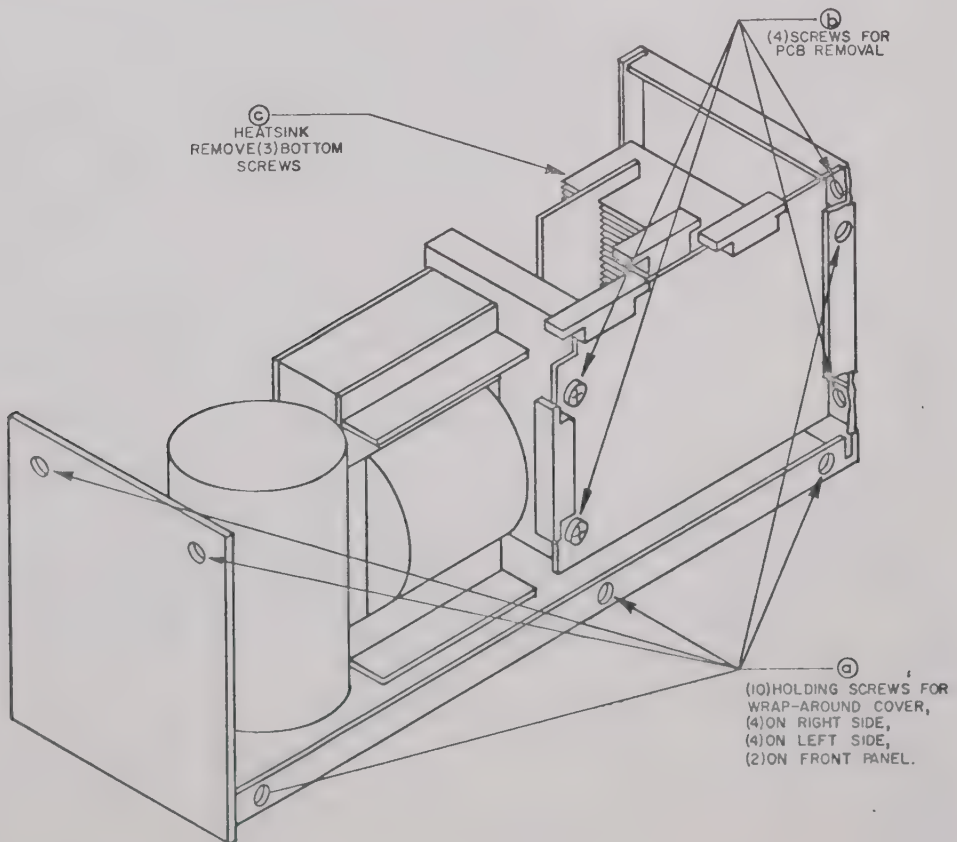


FIG. 5-1 DISASSEMBLY, OPS GROUP IV, V.

5-4 INTERNAL ADJUSTMENT PROCEDURES

5-5 GENERAL. Refer to Section II, Table 2-1 for a listing of *all* adjustment procedures and to FIG. 2-1 for the location of *all* internal controls.

5-6 MAXIMUM OUTPUT CURRENT ("I_O max adj.") ADJUSTMENT. This adjustment determines the absolute maximum of the output current and serves as a calibration for the range of the front panel CURRENT control. The "I_O max adj." (R30) is located on the printed circuit board and is accessible from the rear of the OPS (refer to FIG. 2-1). It is factory-set, so that the front panel control covers an output current range of 2-105% of the maximum rated OPS value. Readjustment of the I_O MAX ADJ. control is needed only if a component in the current control circuitry must be replaced, or if the maximum output current must be set to a lower limiting value. A convenient way to make the adjustment is as follows:

- a) BEFORE turning the a-c power "on," place a short circuit across the output terminals of the OPS Power Supply. Turn VOLTAGE control fully clockwise, turn CURRENT control fully counterclockwise.
- b) Turn a-c power "on." Turn OPS CURRENT control slowly clockwise and observe front panel CURRENT meter. The meter should indicate 105% of the maximum rated output current with the OPS CURRENT control in the maximum clockwise position. If it does *not*, proceed to par. 5-6c.
- c) Locate the I_O MAX control (R30, see Section II, FIG. 2-1 for location) and adjust to 105% of the rated output current. DO NOT ADJUST TO MORE THAN 105% I_O max. Although this might be possible (due to component tolerances), malfunction of the power supply may be caused by exceeding the rated maximum output current value.

5-7 LAG NETWORK AND FEEDBACK CAPACITOR ADJUSTMENT. (See also "Dynamic Adjustments," Section III, par. 3-18). A multiturn rheostat (R32—marked "LAG"), and a adjustable trimmer capacitor (C14—marked "C_f" accessible through holes from the rear of the OPS, refer to Section II, FIG. 2-1) have been provided on all OPS models. these controls ("C_f" and "LAG") have been factory adjusted for maximum dynamic stability of the OPS output, under a variety of gain, feedback and load conditions. Their readjustment is indicated, if instability (high frequency oscillation) is observed at the output terminals of the OPS or at the load and if all other precautions have been observed. The lag network ("LAG") and the feedback capacitor ("C_f") may be adjusted (in any order) to provide dynamic stability for *your* operating conditions by observing the OPS output with an oscilloscope and adjusting "LAG" and "C_f" until the OPS output appears stable again.

5-8 ZERO ADJUSTMENT. A multiturn rheostat (R27—marked "zero"), accessible through a hole from the rear of the OPS (refer to Section II, FIG. 2-1) has been provided on all models. The range of the ZERO control is approximately ± 25 millivolts around the output zero level. The adjustment of the ZERO control has been described for several applications in Section III of this manual.

5-9 OPERATIONAL POWER SUPPLY PERFORMANCE MEASUREMENTS

5-10 GENERAL. Measurements to verify the performance specifications are a frequent requirement of "Incoming Inspection" departments, as a part of a routine maintenance program, or as a part of repair procedures. Some operational power supply measurements (OUTPUT IMPEDANCE, DRIFT, TEMPERATURE COEFFICIENT, etc.) require specialized test equipment and/or a controlled environment, and are therefore not described here. For information on these measurements, consult the Kepco Engineering Test Department. The measurements described in the following paragraphs, require only a minimum of equipment, and are generally sufficient to verify the most important d-c and dynamic performance specifications.

5-11 REQUIRED INSTRUMENTATION

- STABILIZED A-C INPUT SOURCE, with provisions for "stepping" the voltage over the specified a input range (105 to 125V **or** 210 to 250V). A variable AUTOTRANSFORMER is generally adequate if it can deliver the required a-c input current.
- RESISTOR LOAD, variable, capable of dissipating the full d-c output power of the unit under test and equipped with "on-off" and "shorting" switch (S1).
- D-C VOLTAGE MONITOR, digital or differential voltmeter, able to resolve at least 1 microvolt (M1).
- OSCILLOSCOPE, vertical sensitivity at least 10 mV/cm and with a minimum bandwidth of 10 megahertz.
- SQUARE-WAVE GENERATOR, with a variable output amplitude of 0–10 volts into 600 ohms and rise time of at least 0.1 microseconds. A "floating output," where the signal is available either in the positive **or** in the negative direction is desirable.

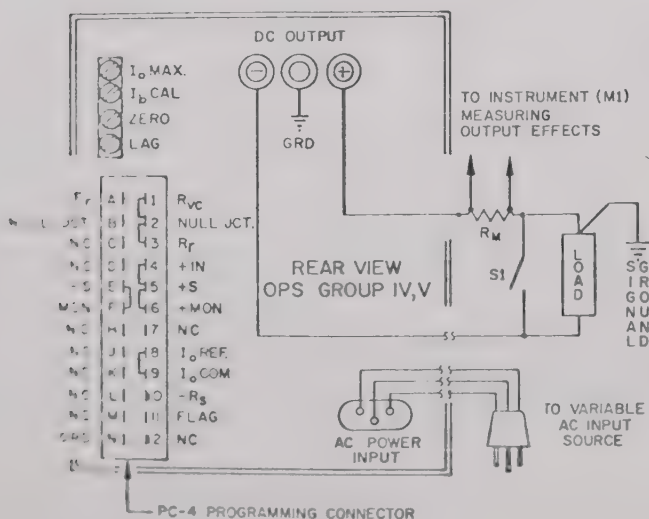
5-12 OUTPUT EFFECT MEASUREMENTS, CURRENT CONTROL CHANNEL. The output effects due to a-c source or d-c load variations in the **current mode** can be measured with the circuit shown in FIG. 5-2. These output effects ("SOURCE" AND "LOAD" EFFECT) are defined as **the amount of output current change, resulting from the specified variation in a-c source voltage, or from a change in load resistance.** The output effects can be expressed as an absolute change (ΔI_O), or as a percentage of the total output current (I_O):

$$\% \text{ OUTPUT EFFECT} = \frac{\Delta I_O}{I_O} (100\%) = \frac{\Delta V_{RM}}{V_{RM}} = (100\%), \text{ where } V_{RM} \text{ is } \dots \text{ (Eq. 5-1)}$$

the voltage drop across the measuring resistor (R_M), and ΔV_{RM} is the **change** observed as S1 is closed or opened.

5-13 PROCEDURE (Refer to FIG. 5-2)

- To measure the SOURCE EFFECT, vary the a-c source voltage over the specified range (105–125V **or** 210–250V) and note the deviation (ΔV_{RM}) on the voltmeter (M1 across R_M).
- To measure the LOAD EFFECT, close the load switch (S1) and note the deviation (ΔV_{RM}) on the voltmeter (M1 across R_M).
- To calculate the present output effect, measure " V_{RM} " and substitute the measured values (V_{RM} and ΔV_{RM}) into the equation (Eq. 5-1).



NOTES:

- Complete ALL connections BEFORE applying a-c power.
- All shorting-links on PC-4 shown SOLID must be CLOSED.
- R_M is a measuring resistor (meter shunt type), 4-terminal network T.C. = 20 ppm or better. It should drop 1 volt at the output current of interest. Wattage: at least 10 times the calculated dissipation.

FIG 5-2 OUTPUT EFFECT MEASUREMENTS CURRENT CONTROL CHANNEL.

5-14 OFFSETS MEASUREMENTS. The specified variations of the offset voltage and the offset current for the voltage control channel (ΔE_{iO} , ΔI_{iO}), can be verified (for a-c source changes) using the circuit shown in FIG. 5-3. These measurements provide a reliable check of the *d-c* performance of the OPS.

NOTES:

- 1) Connect load and external components *before* applying a-c power to the power supply.
- 2) *Alternate* signal ground points may be chosen: refer to par. 3-5d.
- 3) *Twist* all wire pairs. Use shielding as indicated.

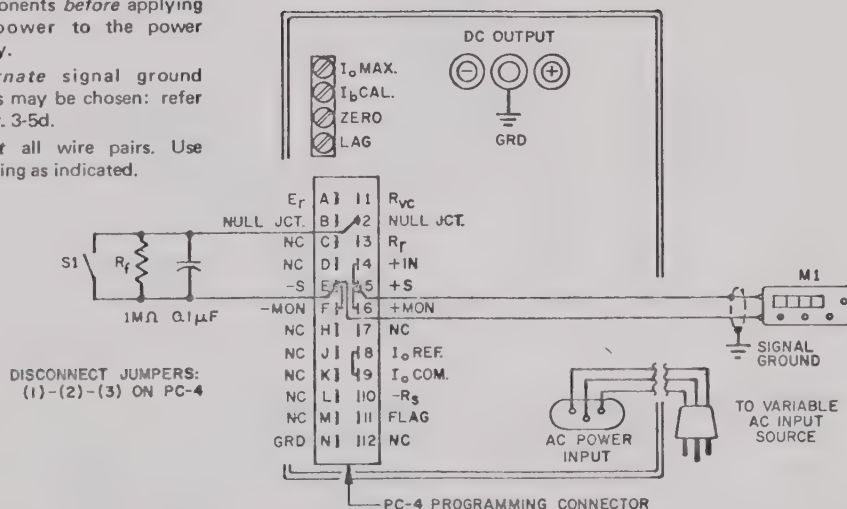


FIG. 5-3 OFFSET MEASUREMENTS (ΔE_{iO} , ΔI_{iO} FOR A-C SOURCE VARIATIONS) VOLTAGE CONTROL CHANNEL.

5-15 PROCEDURE (Refer to FIG. 5-3)

- 1) To measure ΔE_{iO} versus a-c source, *close* S1 and read E_{iO} (offset voltage) on the digital voltmeter (M1) at the output. Vary the a-c input source over the specified range (105–125V *or* 210–250V) and note the *variation* from the initial reading (ΔE_{iO}).
- 2) To measure ΔI_{iO} versus a-c source, *open* S1 and read E_O (output voltage). Since the offset current (I_{iO}) flows through the feedback resistor ($R_f = 1$ M ohm) it generates a measurable voltage (E_O) at the output (1 nanoampere of I_{iO} generates an output voltage of 1 millivolt for example). Vary the a-c input source, over the specified range (105–125V *or* 210–250V) and note the *variation* from the initial reading (ΔI_{iO}).
- 3) The measured offset variations (ΔE_{iO} , ΔI_{iO}) versus A-C Input Source) should be compared to the specified values in Section I of this manual. Disconnect measuring circuit. This completes the *d-c* measurements of the OPS under test.

5-16 DYNAMIC MEASUREMENTS. The specifications for the PROGRAMMING TIME CONSTANT and for the MAXIMUM SLEWING RATE can be verified using the circuit shown in FIG. 5-4.

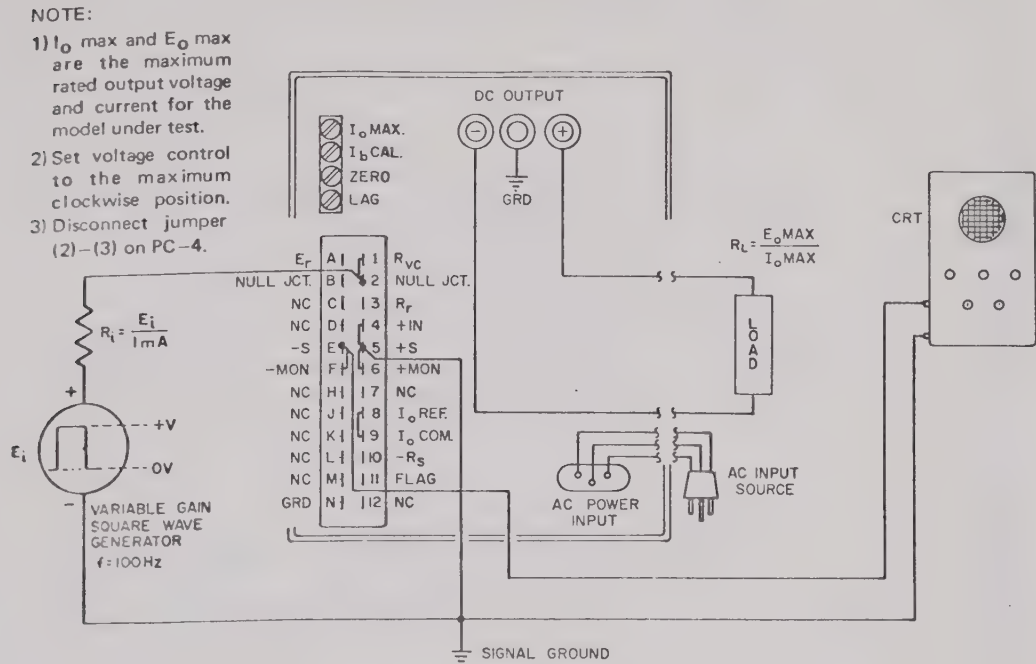


FIG. 5-4 DYNAMIC MEASUREMENTS, UNCOMMITTED CONTROL CHANNEL.

5-17 PROCEDURE (Refer to FIG. 5-4)

- 1) To measure the PROGRAMMING TIME CONSTANT, adjust the gain of the square-wave generator (E_i) until the output waveform (displayed on the oscilloscope) shows a peak amplitude equal to the maximum rated output voltage of the OPS model under test. (Refer to FIG. 5-5.) NOTE: Use *inverted* oscilloscope input.

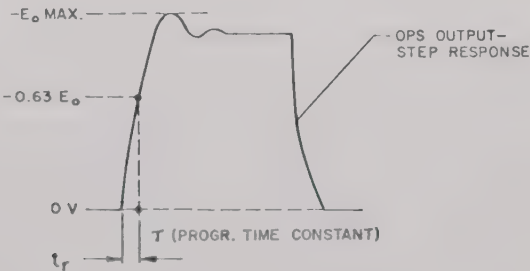


FIG 5-5 OPS OUTPUT WAVEFORM FOR TIME CONSTANT MEASUREMENTS.

NOTE: Measure the rise time of the displayed waveform from zero (0V) to $-0.63 E_o$ = ONE TIME CONSTANT). The time t_r represents the PROGRAMMING TIME CONSTANT.

- 2) To measure the MAXIMUM SLEWING RATE, *decrease* the front panel VOLTAGE control setting and *increase* the gain of the square-wave generator at the input (E_i) until a *distinct break point* in the up-slope of the output waveform becomes visible. The slope from "0V" to this break point is the fastest rate of change of which the OPS under test is capable. Make certain that this is true, by slightly increasing the gain of the square-wave generator. The slope (E_o/t_r) should not change. (Refer to FIG. 5-6).

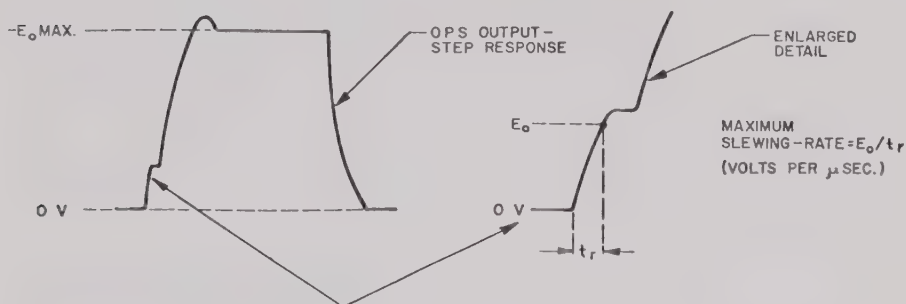


FIG. 5-6 OUTPUT WAVEFORM FOR SLEWING RATE MEASUREMENTS.

- NOTE:** 1) MEASURE " E_o " (ANY CONVENIENT VALUE ON THE SLOPE).
 2) MEASURE " t_r ."
 3) CALCULATE: MAXIMUM SLEWING RATE = E_o/t_r in volts per microseconds.

5-18 TROUBLE SHOOTING

- 5-19 Modern, high performance power supplies have reached a state of sophistication, which requires a thorough understanding of the problems involved in repairing complex, solid-state circuitry. Servicing beyond simple parts replacement should consequently be attempted only by personnel thoroughly familiar with solid-state component techniques and with experience in closed-loop circuitry.
- 5-20 Trouble shooting charts showing resistance and voltage readings are of very limited usefulness with feedback amplifiers and are not included here. Instead, a detailed circuit description (Section IV), parts location diagrams, simplified functional schematics, and a main schematic with all significant voltage readings (Section VI) are presented in this manual.
- 5-21 The following basic steps in case of power supply malfunctioning may be found helpful:
 - a) NO OUTPUT:
 - 1) If power supply does not function at all, check obvious points first. Check a-c input source connections, a-c input source voltage and frequency. (Normally the power supply is connected for 115V a-c service. Check fuse and replace if open.
 - 2) Operate the power supply as a voltage source by connecting the programming connector (PC-4) for standard power supply operation (See Section III, FIG. 3-1). Observe front panel voltmeter. Rotating of the VOLTAGE control through its range should vary the output from zero to the maximum rated value.
 - 3) Check if CURRENT control ($I_o \text{ CONT}$) has been inadvertently misadjusted. Turn CURRENT control to approximately one half its maximum *clockwise* position.
 - 4) Check mating of the internal PC connectors with the PC boards.
 - 5) Check indicated voltage readings on the main schematic, check transistors and start circuit analysis with the help of Section IV.

- b) **HIGH OUTPUT:** Checks number (4) and (5) are also applicable for this condition. In addition, check the following:
- 1) Test main driver and pass element by connecting a 6V dry cell battery: (-) battery to (-) output terminal, (+) battery successively to the common base of the power transistors on Assembly A3, and to the base of the Darlington driver, Q301 or Q305. (See main schematic and component location diagram.) Observe the result on a voltmeter connected across the output. Functioning driver and pass elements should yield readings of approximately 5.3V and 4.7V, respectively. If shorted transistors are suspected, confirm by:
 - A) **Removing** Darlington driver (Q301 or Q303, depending on OPS model) and check if output is still high:
 - a) If it is, check series pass transistors by testing with an ohmmeter from emitter to collector. Polarity reversal on the meter leads should produce an approximate 1:4 resistance ratio on "good" transistors. Replace only with listed types, if defective.
 - b) If output goes to zero after driver (Q301 or Q303) is remove, check this transistor and concentrate on the main amplifier board (A1). Check Q1 and IC's, look for burned components and replace if necessary.
- c) **POOR PERFORMANCE:**
- 1) Excessive output or offset variations are often due to incorrectly connected loads or faulty measurement techniques. Perform measurements only as directed in Section V and follow the connection diagrams.
 - 2) High frequency oscillations at the output are often due to improperly adjusted lag networks (see par. 5-8) or to loads with large inductive or capacitive components and/or long load wires. (Maximum allowable capacitance loading = 1000 pF.) Tightly twisted load wires of sufficient diameter and kept as short as possible are often the solution to the problem. *In extreme cases*, connect an additional feedback capacitor from PC -4, terminal 2, B to PC -4 terminal E. **NOTE: THE DYNAMIC SPECIFICATIONS ARE NOW NO LONGER APPLICABLE.**
 - 3) High ripple at the output or at the load may be caused by ground loops or long load wires passing through magnetic fields. Grounding of one side of the output and careful lead dressing are often helpful. (Refer to Section III, par. 3-5d for more signal grounding information.)
- !) **KEPCO Field Engineering Offices or the KEPCO Applications Engineering Department are always available for consultation or direct help in difficult service or application problems.**

SECTION VI — ELECTRICAL PARTS LIST AND DIAGRAMS

6-1 GENERAL

- 6-2 This section contains the main schematic, the parts location diagrams, and a list of all replaceable electrical parts. All components are listed in alpha-numerical order of their reference designations. Consult your Kepco Representative for replacement of parts not listed here.

6-3 ORDERING INFORMATION

- 6-4 To order a replacement part or to inquire about parts not listed in the parts list, address order or inquiry either to your authorized Kepco Sales Representative or to:

KEPCO, INC.
131—38 Sanford Avenue
Flushing, N.Y. 11352

- 6-5 Specify the following information for each part:

- a) Model and complete serial number of instrument.
- b) Kepco part number.
- c) Circuit reference designator.
- d) Description.

- 6-6 To order a part not listed in the parts list, give a complete description and include its function and location.



KEPCO. REPLACEMENT PARTS LIST

MAIN PRINTED CIRCUIT BOARD ASSEMBLY (A1), MODEL OPS 100-1M

Code 7-373

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C1	1	Capacitor,Elect.,Axial Leads 15 μ F, 200V	Sprague Type 38D	117-0623	1
C2	1	Capacitor,Elect.,Axial Leads 150 μ F, 15V	Sangamo Type 556	117-0677	1
C3,6,7,8,9	5	Capacitor,Mylar,Axial Leads 0.001 μ F, 200V	Sprague Type 192P	117-0570	1
C5	1	Capacitor,Elect.,Axial Leads 200 μ F, 50V	Sangamo Type 052	117-0651	1
C10,11	2	Capacitor,Elect.,Axial Leads 150 μ F, 3V	Sangamo Type 556	117-0512	2
C12	1	Capacitor,Mylar,Axial Leads 4700 pF, 200V, 10%	Wesco Type 32M	117-0588	1
C13	1	Capacitor,Metal,Axial Leads 0.05 mF, 200V	Sprague Type 192P	117-0315	1
C14	1	Capacitor,Variable 1200 pF, 175V	Arco T521317-1	117-0592	1
C15	1	Capacitor,Mylar,Pigtail 2200 pF, 200V	Sprague Type 192P	117-0659	1
C16,9,12, 13,15,18,19	8	Silicon,Rectifier,Pigtail	Semicon Type SI-4	124-0028	1
C17	1	Rectifier Diode,Si.,Axial Leads 100V, PIV, 1A	Semicon Type SI-1	124-0133	4
C18	1	Bridge Rectifier,Silicon 100V, PIV	General Instrument Type W-02	124-0346	1
C19	1	Zener Diode 6.5V, $\pm$ 5%	Motorola 121-0028	121-0028	1
C20	1	Zener Diode 12V, $\pm$ 10%	Motorola 121-0058	121-0058	1
C21	1	Zener Diode 12V, $\pm$ 10%	Motorola 121-0012	121-0012	1
C22	1	Zener Diode 3.3V, $\pm$ 5%	Motorola 121-0060	121-0060	1
C23	2	Zener Diode 6.2V, $\pm$ 5%	Motorola 121-0062	121-0062	1
C24	2	Rectifier Diode,Si.,Axial Leads	Semicon 124-0178	124-0178	1
C25	5	I.C. Operational Amplifier	Texas Instruments 250-0025	250-0025	2
C26	1	Transistor,Silicon,NPN	Semiconductor 119-0094	119-0094	1
C27	2	Transistor,Silicon,PNP	Fairchild 2N5138	119-0096	1
C28	1	Transistor,Silicon,NPN	Fairchild 2N5133	119-0093	1

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS REPRESENTS AT THE TIME OF THE LISTING. KEPCO DOES NOT GUARANTEE THE QUALITY OF EQUIVALENT PARTS. KEPCO, INC. RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES.



KEPCO. REPLACEMENT PARTS LIST

MAIN PRINTED CIRCUIT BOARD ASSEMBLY (A1), MODEL OPS 100-1M

Code 5-873

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
R1	1	Resistor,Fixed,Power Axial 20 k ohm, 5 W, 5%	Tepro Type TS-5W	115-1833	1
R2	1	Resistor,Fixed,Molded 2.2 k ohm, 1/4 W, 10%	Int. Resistance Type RG-1/4	115-2382	1
R3	1	Resistor,Fixed,Molded 10 ohm, 1/4 W, 10%	Int. Resistance Type RG-1/4	115-2230	1
R4,5	2	Resistor,Fixed,Molded 560 ohm, 1/2 W, 5%	Allen Bradley EB5615	115-0888	1
R6	1	Resistor,Fixed,Precision,M.F. 3.01 k ohm, 1/8 W, 1%	Dale Type MFF-1/8	115-2214	1
R7,8	2	Resistor,Fixed,Precision,M.F. 6.04 k ohm, 1/8 W, 1%	Dale Type MFF-1/8	115-2175	1
R9	1	Resistor,Fixed,Molded 300 ohm, 1/2 W, 5%	Allen Bradley EB3015	115-0783	1
R10	1	Resistor,Fixed,Molded 43 ohm, 1/2 W, 5%	Allen Bradley EB4305	115-2123	1
R11	1	Resistor,Fixed,Molded 1.3 k ohm, 1/2 W, 5%	Allen Bradley EB1325	115-1600	1
R12,13	2	Resistor,Fixed,Molded 10 k ohm, 1/4 W, 10%	Int. Resistance Type RG-1/4	115-2211	1
R14	1	Resistor,Fixed,Molded 620 ohm, 1 W, 5%	Allen Bradley GB6215	115-0496	1
R15	1	Resistor,Fixed,Molded 180 k ohm, 1/4 W, 10%	Int. Resistance Type RG-1/4	115-2508	1
R16,20,21	3	Resistor,Fixed,Molded 1 k ohm, 1/4 W, 10%	Int. Resistance Type RG-1/4	115-2238	2
R17,26	2	Resistor,Fixed,Molded 4.7 k ohm, 1/4 W, 10%	Int. Resistance Type RG-1/4	115-2383	1
R18	1	Resistor,Fixed,Precision,M.F. 43.2 k ohm, 1/8 W, 1%	Int. Resistance Type CEA	115-2380	1
R19,27	2	Resistor,Variable,Cermet 10 k ohm, 3/4 W, 10%	Bourns Type 3009P	115-2481	1
R22	1	Resistor,Fixed,Precision,M.F. 732 ohm, 1/2 W, 1%	Dale Type MFF-1/2	115-2081	1
R23	1	Resistor,Fixed,Precision,M.F. 30.1 k ohm, 1/8 W, 1%	Dale Type MFF-1/8	115-2541	1
R24	1	Resistor,Fixed,Precision,M.F. 93.1 k ohm, 1/8 W, 1%	Dale Type MFF-1/8	115-2553	1
R25	1	Resistor,Fixed,Precision,M.F. 15 k ohm, 1/4 W, 1%	Dale Type MFF-1/4	115-1813	1
R28	1	Resistor,Fixed,Precision,M.F. 48.7 k ohm, 1/8 W, 1%	Dale Type MFF-1/8	115-2554	1
R29	1	Resistor,Fixed,Precision,M.F. 392 ohm, 1/4 W, 1%	Dale Type MFF-1/4	115-2060	1
R30	1	Resistor,Variable,W.W. 1 k ohm, 1 W, 10%	Bourns Type 3009P	115-2264	1
R31	1	Resistor,Fixed,Precision,W.W. 5.7 k ohm, 1 W, 1%	Tepro Type TS-1W	115-1301	1

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THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS REPRESENTS A SUGGESTION FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.



KEPCO. REPLACEMENT PARTS LIST

MAIN PRINTED CIRCUIT BOARD ASSEMBLY (A1), MODEL OPS 100-1M

Code 5-873

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
R32	1	Resistor, Variable, Cermet 200 ohm, 3/4 W, 10%	Bourns Type 3009P	115-2569	1
R33	1	Resistor, Fixed, Molded 1.5 k ohm, 1/4 W, 10%	Int. Resistance Type RG-1/4	115-2229	1
R34	1	Resistor, Fixed, Molded 2.7 k ohm, 1/2 W, 10%	Allen Bradley EB2721	115-0560	1
R35	1	Resistor, Fixed, Molded 100 ohm, 1/4 W, 10%	Int. Resistance Type RG-1/4	115-2231	1
R36	1	Resistor, Fixed, Molded 330 ohm, 1/4 W, 10%	Int. Resistance Type RG-1/4	115-2233	1

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KEPCO. REPLACEMENT PARTS LIST

Code 7-1873

FRONT PANEL ASSEMBLY (PART OF A2), MODEL OPS 100-1M

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C101	1	Capacitor, Ceramic, Disc. 0.0022 mF, 200V	Sprague Type 192P	117-0659	1
CB101	1	Circuit Breaker	Airpax 127-0305	127-0305	1
DS101,102	2	Mode Indicator Lamp	Drake 152-0071	152-0071	3
M101	1	Meter 0-1 Amperes	Ammon 135-0430	135-0430	0
M102	1	Meter 0-100 Volts	Ammon 135-0444	135-0444	0
R101	1	Resistor, Variable (10-Turn Pot.) 100 k ohm, 2 W, 5%	Bourns Type 3507	115-1645	1
R102	1	Resistor, Variable (10-Turn Pot.) 10 k ohm, 2 W, 5%	Bourns Type 3507	115-1234	1
S101,102	2	Switch, DPDT	Stackpole Type SS-72-1	127-0254	0

* THIS REPLACEMENT PART MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

* THE MFRS. NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS REPRESENTS AT
THE TIME THIS LIST WAS PREPARED THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING
EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.



KEPCO. REPLACEMENT PARTS LIST

MAIN CHASSIS ASSEMBLY (A2), MODEL OPS 100-1M

Code 5-873

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
B201	1	Fan Motor	Howard Industries Model 21075	148-0026	1
NONE	1	Fan Blade	Howard Industries 149-0019	149-0019	0
C201	1	Capacitor,Elect.,Can-Type 2.4 k μ F, 200V d-c	General Electric Type 86F	117-0634	1
C202	1	Capacitor,Ceramic,Disc. 0.05 μ F, 500V	Radio Materials Type JG	117-0163	1
CR201	1	Rectifier,Stud Mount PIV 200V, 15A	Westinghouse 409 D	124-0352	1
R201	1	Resistor,Fixed,Molded 7.5 k ohm, 5 W, 5%	Tepro Type TS-5W	115-2443	1
R202	1	Resistor,Fixed,Power Strip 4 k ohm, 20 W, 5%	Memcor MOR20-4000	115-0958	1
R203	1	Resistor,Fixed,Power Strip 1.5 k ohm, 20 W, 5%	Ward Leonard 20S1500	115-0923	1
S201	1	Switch,Slide,DPDT	Switchcraft 127-0294	127-0294	0
T201	1	Transformer,Power	Kepco Magnetics 100-2009	100-2009	1

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

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KEPCO. REPLACEMENT PARTS LIST

HEAT SINK ASSEMBLY (A3), MODEL OPS 100-1M

Code 7-1873

REFERENCE DESIGNATION	QTY.	DESCRIPTION	MFRS. NAME & PART NO. SEE BOTTOM NOTE	KEPCO PART NO.	REC. SPARE PART QTY.
C301,302	2	Capacitor,Ceramic,Disc. 0.01 μ F, 500V	Radio Materials Style B	117-0084	1
C303	1	Capacitor,Mylar,Axial Leads 0.0022 μ F, 200V	Sprague Type 192P	117-0659	1
CR301,302	2	Rectifier,Diode PIV, 100V	Semicon Type S-5A4	124-0348	1
Q301,302, 303,304	4	Transistor,Silicon,NPN	Westinghouse 119-0070	119-0070	1
Q305	1	Transistor,Silicon,NPN	Westinghouse 119-0071	119-0071	1
R301,302, 303,304	4	Resistor,Fixed,Power Axial 2 ohm, 3 W, 3%	Tepro Type TS-3W	115-2141	1
R305	1	Resistor,Fixed,Precision 1 ohm, 5 W, 1%	Tepro Type TSK-5W	115-2200	1
R306	1	Resistor,Fixed,Molded 100 ohm, 1/4 W, 10%	Int. Resistance Type RG-1/4	115-2231	1
R307	1	Resistor,Fixed,Molded 470 ohm, 1/4 W, 10%	Int. Resistance Type RG-1/4	115-2235	1

MISCELLANEOUS

4	Plastic Feet	Kepco, Inc. 158-0003	158-0003	—
1	Power Input Connector	Tower 1061-2	143-0249	—
1	Binding Post, Red	Superior 0F21RC	151-0041	—
1	Binding Post, Black	Superior 0F21BC	151-0042	—
1	Binding Post, Green	Superior 0F21GNC	151-0044	—
1	Programming Connector	Cinch 251-12-30-160	143-0273	—
1	Shell For Above	Kepco, Inc. 204-0005	204-0005	—
2	Control Knob, Black	Kepco, Inc. 155-0052	155-0052	—
1	Cover	Kepco, Inc. 129-0141	129-0141	—
1	Line Cord	Kepco, Inc. 118-0441	118-0441	—

NOTE: REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

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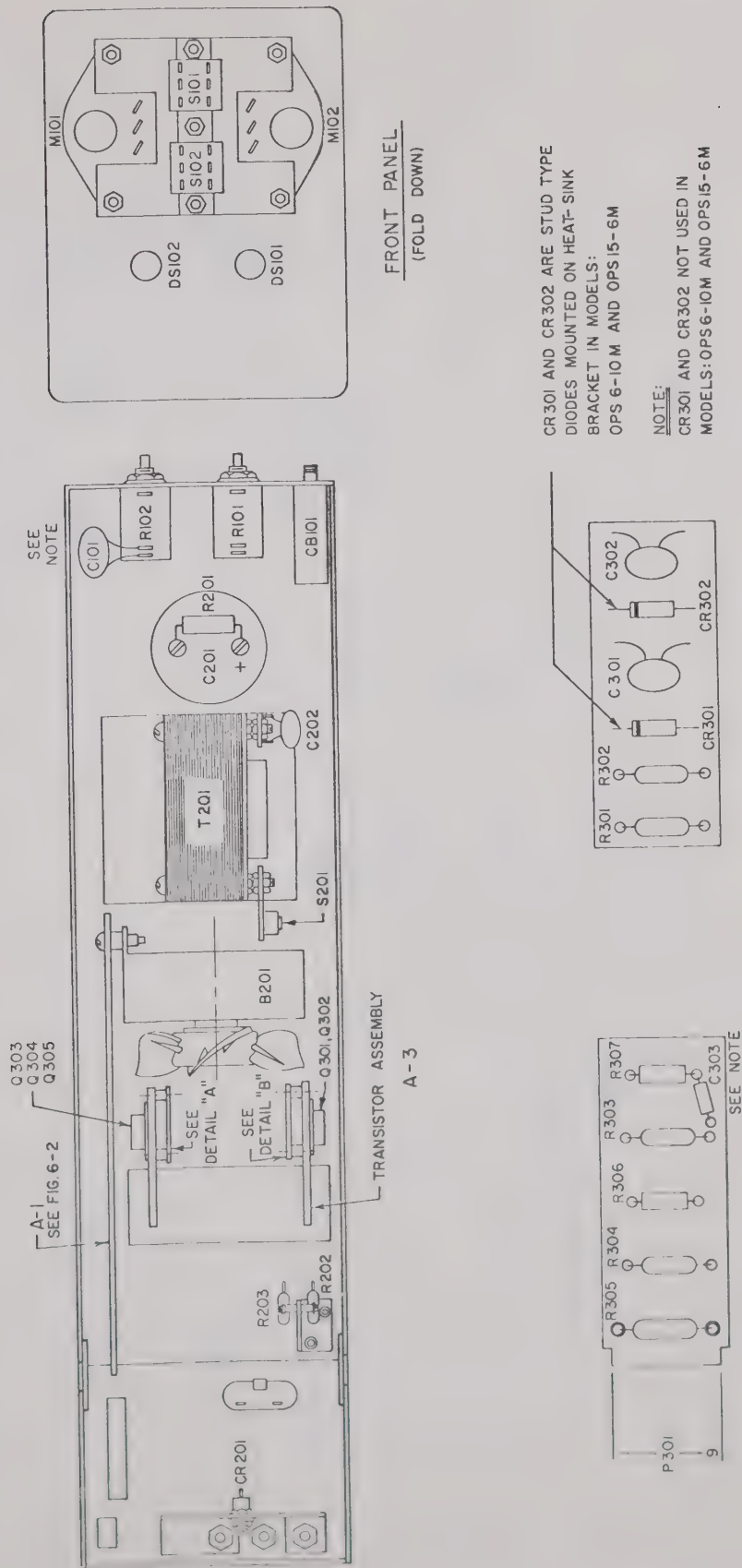
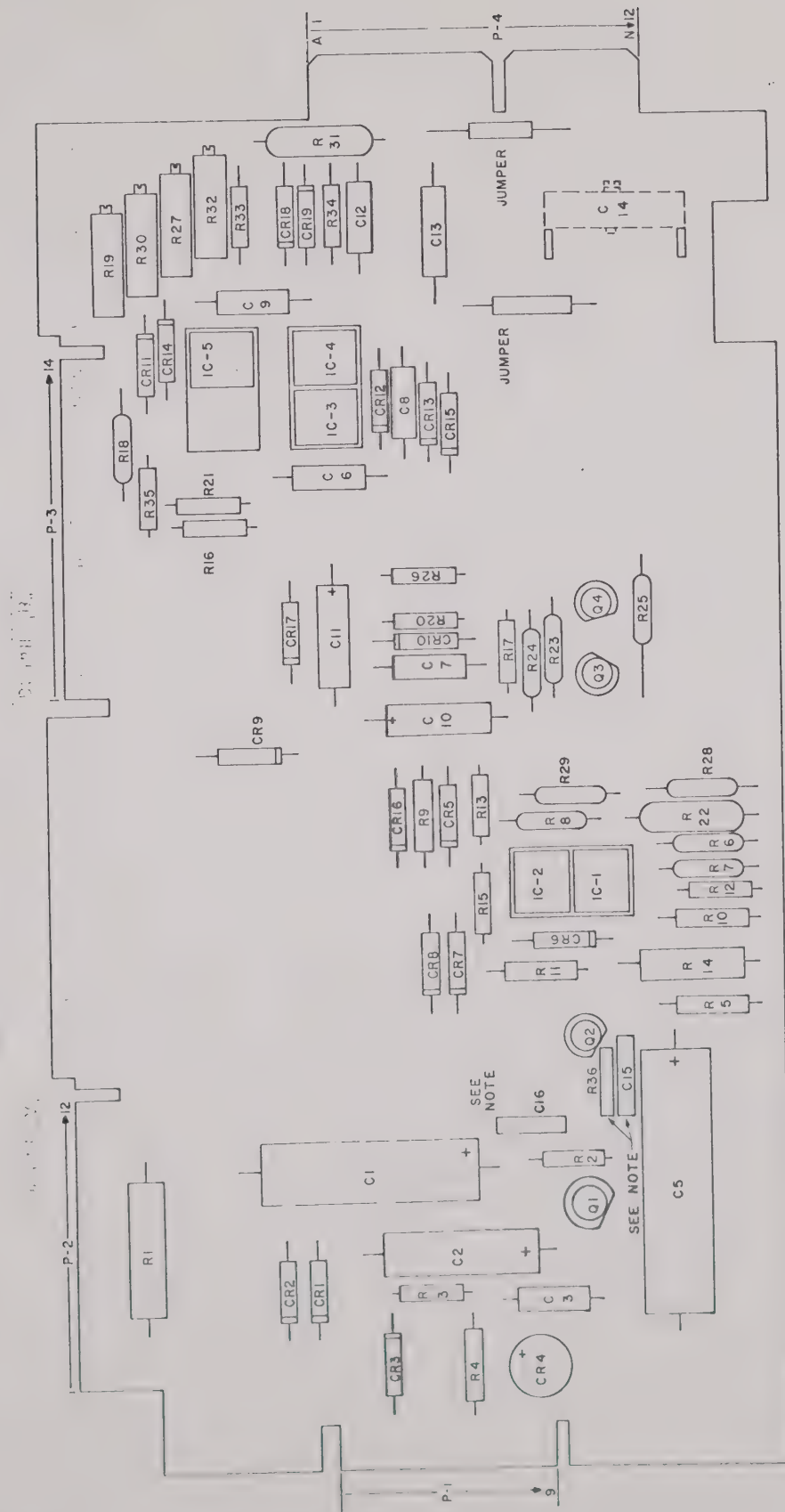
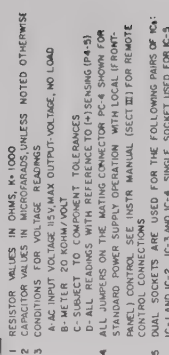


FIG. 6-1 MAIN CHASSIS (A2) AND HEAT SINK (A3) ASSEMBLIES, COMPONENT LOCATION.

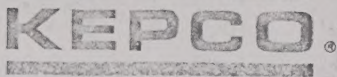
FIG. 6-2 PRINTED CIRCUIT BOARD (A1), COMPONENT LOCATION.



NOTES: R36, C15 AND C16 NOT USED IN ALL MODELS,
SEE MAIN SCHEMATIC.



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INSTRUCTION MANUAL CORRECTION

Please note the following corrections to the Manual Material as indicated:

Parts List and Schematic Diagram:

- | | | | | | |
|----|---------|------|------------------------|---------------|---------------------|
| 1. | CHANGE: | IC-1 | Operational, Amplifier | | Kepco #250-0025 to: |
| | | IC-1 | Operational, Amplifier | | Kepco #250-0047. |
| 2. | CHANGE: | CR8 | Zener Diode | 12v $\pm$ 10% | Kepco #121-0012 to: |
| | | CR8 | Zener Diode | 10v $\pm$ 10% | Kepco #121-0078. |

OPS 100-1M/11-1373/r3 C3153



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